UNIVERSIDADE DE LISBOA

Instituto de Geografia e Ordenamento do Território

CHEIAS E INUNDAÇÕES: AVALIAÇÃO, IMPACTOS E INSTRUMENTOS PARA A GESTÃO DO RISCO

Pedro Manuel Pinto dos Santos

Orientadores: Prof. Doutor Eusébio Joaquim Marques dos Reis
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Tese especialmente elaborada para a obtenção do grau de doutor no ramo de Doutoramento em Território, Risco e Políticas Públicas

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2015

"Quando o rio transborda, ele não se assusta;

Fica tranquilo, mesmo que um Jordão lhe entre pela boca."

Livro de Job 40, 23

Agradecimentos

Uma tese de doutoramento é, frequentemente, o resultado de um longo trabalho individual. Esta individualidade está até certo ponto presente na minha tese mas este documento reflete, contudo, muito mais de trabalho em equipa que de trabalho de uma pessoa apenas. Correndo o risco de não mencionar todos e todas ou de não as mencionar devidamente, gostaria de fazer publicamente este agradecimento àqueles que direta ou indiretamente me ajudaram a levar este projeto a bom porto.

Logo à partida, aos meus dois orientadores, Professor Eusébio Reis e Professor Alexandre Oliveira Tavares. A tese nunca seria concluída sem o seu incentivo amigo e prático, a sua qualidade, experiência e exigência científica, a sua compreensão para os meus atrasos e dúvidas.

Alargando a base de sustentação do argumento de que este é o resultado de um coletivo, a presente tese só se torna possível devido à minha integração em diversos projetos de investigação científica, a diferentes escalas geográficas e em diferentes temáticas, todas elas enquadradas nas chamadas Ciências do Risco, e tendo com maior ou menor intensidade a presença do risco de cheias e inundações. Considero justa a referência aqui a esses mesmos projetos, por ordem cronológica do seu início:

- Cartografia de zonas inundáveis no município de Soure, pelo Departamento de Ciências da Terra da Universidade de Coimbra, para o Município de Soure;

- Ações de prevenção e gestão dos riscos naturais e tecnológicos no concelho de Alvaiázere – RiscAL, pelo Departamento de Ciências da Terra da Universidade de Coimbra, para o Serviço Municipal de Proteção Civil do Município de Alvaiázere;

- Avaliação de riscos naturais no município de Torres Novas, pelo Centro de Estudos de Geografia e Ordenamento do Território da Universidade de Coimbra;

- DISASTER - Desastres naturais de origem hidro-geomorfológica em Portugal: base de dados SIG para apoio à decisão no ordenamento do território e planeamento de emergência (PTDC/CS-GEO/103231/2008), pelo Centro de Estudos Sociais da Universidade de Coimbra, sendo o projeto coordenado a nível nacional pelo Instituto de Geografia e Ordenamento do Território da Universidade de Lisboa e tendo como parceiro também o Departamento de Geografia da Universidade do Porto;

- MOLINES - Modelação da inundação em estuários. Da avaliação da perigosidade à gestão crítica (PTDC/AAG-MAA/2811/2012, pelo Centro de Estudos Sociais da Universidade de Coimbra, sendo o projeto coordenado a nível nacional pelo Laboratório Nacional de Engenharia Civil e tendo como parceiro também a Autoridade Nacional de Proteção Civil.

Destes projetos resultaram alguns dos trabalhos apresentados na tese, e de outros não, mas o que é relevante em todos eles é o facto de me terem proporcionado a envolvência no ambiente e no espírito certo, para que eu pudesse crescer e alargar os meus horizontes de geógrafo e em concreto nas Ciências do Risco.

Um agradecimento especial à minha Família, e de um modo único aos meus "pequenos" sobrinhos que, com a sua sã e bonita naturalidade, me interrompiam nos momentos certos e "incertos" permitindo-me manter a minha própria sanidade e boa disposição...!

Um apoio algo idêntico me deram os meus "amigos de Mem Martins" e os "amigos de Coimbra". Estando ou não muitos deles envolvidos em programas doutorais, na Geografia ou de muitas outras áreas científicas – desde a Química à Psicologia –, foram sempre latos em motivação e boa preocupação.

Uma referência particular aos meus colegas de doutoramento daquele especial primeiro ano e anos seguintes, com quem travei uma relação de amizade também: Adib, António, Daniel, Eduardo, Ermenando, Hector, Jorge, José Manuel, Liliane, Luís, Manuel João, Rosa, Susana, Valentim.

Agradeço aos docentes que nos acompanharam nesse ano, tendo contudo que realçar os Professores José Luís Zêzere, José Manuel Mendes e Lúcio Cunha por terem contribuído para a minha mais ampla compreensão de tudo o que envolve a governação do risco.

A todos no Centro de Estudos Sociais e no Departamento de Ciências da Terra da Universidade de Coimbra, bem como no Instituto de Geografia e Ordenamento do Território da Universidade de Lisboa que tão bem me acolheram, sempre ajudaram, nunca complicaram e permitiram, assim, que eu desenvolvesse a minha atividade de doutorando também.

A todos os que por esquecimento não referi mas que foram igualmente importantes, ao "deus desconhecido" e ao Deus conhecido, obrigado!

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Resumo

O presente trabalho dedica-se ao estudo de diferentes componentes do processo de governação do risco de cheias e inundações. Do lado da avaliação do risco, explora-se em particular a avaliação da suscetibilidade e da perigosidade, e a aplicação de bases de dados de perdas devidas a cheias e inundações na busca da melhor compreensão dos processos que causam o risco. A passagem para o estudo da gestão do risco baseia-se significativamente na relevância das referidas bases de dados, bem como na análise geográfica dos contextos territoriais – físicos e societais – onde o perigo e os impactos se manifestam. No seu todo, ambas as componentes são integradas e discutidas segundo o modelo de governação do risco proposto pelo *International Risk Governance Council*. À luz desse modelo, é realizada uma leitura da Diretiva Inundações e propostos caminhos para a sua implementação, construtores de comunidades resilientes ao risco de cheias e inundações.

A aplicação complementar de diferentes metodologias de avaliação da suscetibilidade e da perigosidade é a melhor forma de compreender o processo de perigo, considerando as diferentes escalas espaciais e temporais em que atuam os fatores físicos e societais que condicionam a sua manifestação. A análise do registo de impactos associado à análise do contexto geográfico onde perigo e impactos ocorrem constituem uma abordagem produtora de conhecimento útil para a tomada de decisão na gestão do risco, quer à escala local quer à escala da bacia hidrográfica.

Destaca-se como positivo o paralelismo entre o novo quadro de avaliação e gestão do risco de cheias e inundações saído da Diretiva Inundações e o modelo de governação do risco, contudo, alguns aspetos do primeiro deverão ser adicionalmente considerados, concretamente: a fase de análise e ponderação do conhecimento produzido na fase de avaliação; e a fase sempre presente de envolvimento público e de partes interessadas, de modo a assegurar o carácter público, transdisciplinar, multiescalar e multissectorial da participação na governação.

Palavras-chave: cheias e inundações, avaliação, impactos, governação do risco.

Abstract

This work is devoted to the study of the different components of the process of flood risk governance. On the side of risk assessment, the evaluation of susceptibility and hazard is particularly explored, as well as the application of flood loss databases in the quest for a better understanding of the processes that cause the risk. The passage to the study of risk management is based significantly on the relevance of such databases as well as the geographical analysis of the territorial context - physical and societal - where hazard and losses take place. On the whole, both components are integrated and discussed under the risk governance model proposed by the International Risk Governance Council. In light of this model, a reading of the Floods Directive is carried out, and ways for its implementation that can lead to building more flood resilient communities are proposed.

The complementary application of different methodologies for assessing susceptibility and hazard is the best way to understand the flooding process, by considering the different spatial and temporal scales, in which the physical and societal factors that influence its manifestation operate. The analysis of flood losses, associated with the analysis of the geographical context in which hazard and losses occur, constitute an approach which results in useful knowledge for decision-making in risk management, not only at the floodplain level but also at the river basin scale. It stands out as positive the parallels between the new European framework for flood risk assessment and management emanated by the Floods Directive and the presented risk governance model, however, some aspects of the framework should be further considered, namely: the analysis and judgment of the knowledge produced in the assessment phase; and the ever-present phase of public and stakeholders' involvement, in order to ensure the public, interdisciplinary, multi-scale and multi-sector nature of participation and communication in governance.

Keywords: flood, hazard, assessment, impacts, risk governance.

1 Introdução

1.1 Contextualização da investigação

Em 2007, a União Europeia assumiu um novo e uniformizado quadro para a avaliação e gestão dos riscos de inundações para todos os seus estados-membros. Tal quadro, definido na Diretiva 2007/60/CE, do Parlamento Europeu e do Conselho, de 23 de outubro, e transposto para o direito interno pelo Decreto-Lei n.º 115/2010, de 22 de outubro, introduz um conjunto de desafios aos quais a comunidade científica não pode e não deve ser alheia.

O quadro aprovado evidencia a importância da elaboração de cartografia de risco de cheias e inundações, a partir da qual se definirão os respetivos planos de gestão. Os desafios colocados com a elaboração destes instrumentos de planeamento – a opção por medidas não estruturais, a possibilidade de proceder a inundações controladas, a escala de análise adotada, a articulação com os planos de ordenamento e planos de emergência de proteção civil – demonstram a pertinência da presente tese, quanto à produção de conhecimento que permita uma melhor ligação entre os processos de avaliação e de gestão do risco, enquadrados em modelos de governação do risco.

Uma parte substancial do trabalho seguidamente apresentado foi conduzido no âmbito ou na sequência de um projeto de investigação científica financiado pela Fundação para a Ciência e Tecnologia, o projeto "DISASTER - Desastres naturais de origem hidro-geomorfológica em Portugal: base de dados SIG para apoio à decisão no ordenamento do território e planeamento de emergência" (PTDC/CS-GEO/103231/2008), do qual o Instituto de Geografia e de Ordenamento do Território da Universidade de Lisboa foi o coordenador nacional, tendo como parceiros o Centro de Estudos Sociais da Universidade de Coimbra, o Departamento de Geografia da Universidade do Porto e o Instituto Dom Luiz da Universidade de Lisboa. Com efeito, a referida base de dados de desastres devidos a processos de cheia e inundação e movimentos de massa em vertente constituiu o ponto de partida para diversos estudos posteriores, nos quais o candidato teve a oportunidade de participar. Nestes estudos se concretizou o aprofundamento da avaliação da suscetibilidade e perigosidade e da análise de impactos e vulnerabilidade a processos de cheia e inundações, em diferentes contextos geográficos.

As áreas geográficas que são objeto dos vários trabalhos apresentados situam-se maioritariamente na região Centro de Portugal, havendo igualmente estudos realizados tendo como âmbito geográfico a totalidade do território de Portugal Continental. De entre as áreas locais estudadas incluem-se as bacias hidrográficas dos rios Vouga, Mondego, Lis, Águeda e Arunca, as regiões do Baixo Mondego e de parte da Beira Interior (23 municípios), e os municípios de Alvaiázere e Torres Novas (Figura 1).

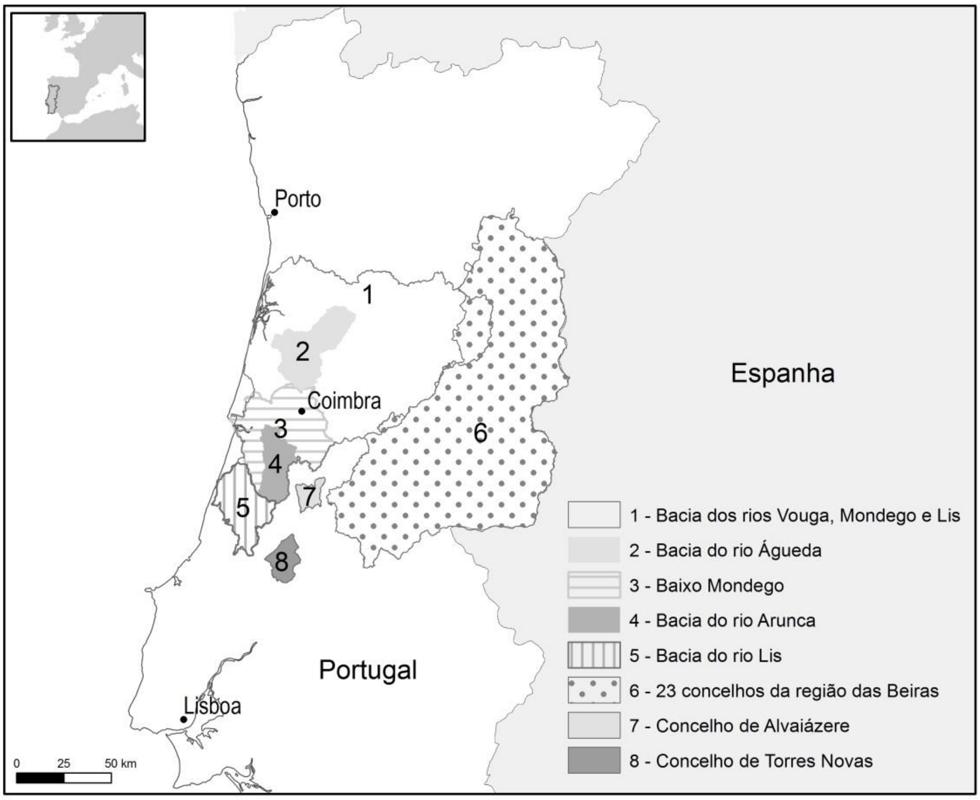

Figura 1. Áreas geográficas estudadas no âmbito da tese.

1.2 Objetivos gerais e específicos

O objetivo geral deste trabalho é a aquisição e divulgação de conhecimento nas áreas de avaliação e gestão do risco de cheias e inundações, que contribua para uma melhor compreensão e resolução dos problemas causados por estes processos inevitáveis, ou seja, para uma mais eficiente governação do risco.

A partir deste objetivo maior decorrem os seguintes objetivos específicos:

- Aplicar diferentes metodologias de avaliação da suscetibilidade e da perigosidade a cheias e inundações, compreender as mais-valias de cada uma e identificar as vantagens do seu uso complementar;
- Caracterizar e compreender o registo histórico de impactos devidos a cheias e inundações;
- Relacionar as condições que geram a propensão para a inundação com a distribuição temporal e espacial de impactos;
- Explorar métodos de utilização de bases de dados de perdas devidas a cheias e inundações, na sua relação com o contexto territorial onde ocorrem, com a finalidade de produzir conhecimento utilizável nos instrumentos de gestão do risco;
- Propor práticas de gestão do risco adequadas às características territoriais das bacias hidrográficas;
- Contribuir para uma mais ampla e eficiente implementação da Diretiva 2007/60/CE – igualmente referida ao longo do texto como Diretiva Inundações – em Portugal, explorando o potencial deste novo quadro legal para o aumento da resiliência às cheias e inundações.

1.3 Organização

Para dar resposta a estes objetivos, a tese está organizada em três grandes partes:

- Parte I – Enquadramento

A Parte I é composta por 5 capítulos, nos quais se contextualizam os objetivos gerais e específicos da tese. Inicialmente é feita uma apresentação da problemática das cheias e inundações (capítulo 2). De seguida, no capítulo 3, traça-se o quadro de governação de risco a partir do qual se estruturam e compreendem os capítulos seguintes. No capítulo 4 apresentam-se os principais métodos de avaliação da suscetibilidade e perigosidade a cheias e inundações. No capítulo 5 é descrita a relevância, estrutura e aplicações de bases de dados de perdas devidas a cheias e inundações. Finalmente, o capítulo 6 apresenta as principais medidas de gestão do risco, com enfoque nas medidas não estruturais.

- Parte II – Resultados

A breve reflexão que se realizou na primeira parte, relativa a algumas das componentes da governação do risco de cheias e inundações, serve igualmente o propósito de contextualizar os resultados que foram obtidos, e que são apresentados nesta parte. Assim, a Parte II encontra-se organizada do seguinte modo: avaliação da suscetibilidade e perigosidade (capítulo 7), análise do registo histórico de perdas por cheias e inundações (capítulo 8), caminhos e desafios para a gestão do risco de cheias e inundações (capítulo 9).

Os resultados são apresentados sobre a forma de artigos originais, classificados em artigos basilares e artigos de suporte: os primeiros são incluídos impressos em anexo (Anexo B1 a B3 - Trabalhos de Investigação Originais), de modo integral e tal como publicados, bem como são fornecidos em suporte digital. Os segundos, são brevemente descritos nesta Parte II e apenas disponibilizados em suporte digital.

Complementarmente aos resultados apresentados em cada artigo, em cada um deles encontram-se capítulos introdutórios e de discussão, específicos ao tema particular que é abordado nesse artigo.

- Parte III – Discussão

A última parte é dedicada a discutir aspetos parcelares e de conjunto tratados na Parte II: avaliação da suscetibilidade e da perigosidade (capítulo 10), avaliação de perdas (capítulo 11) e gestão do risco (capítulo 12). Em todos os capítulos, mas em particular neste último (capítulo 12), é dada ênfase à análise da Diretiva Inundações na perspetiva das fases de governação do risco.

Parte I - ENQUADRAMENTO

2 A problemática das cheias e inundações

O conhecimento atual sobre os processos pelos quais ocorre a inundação de áreas que não estão normalmente cobertas por água está relativamente bem consolidado e aprofundado. Esses processos são eminentemente naturais podendo, contudo, verificar-se a ação de fatores condicionantes ou desencadeantes de origem humana. Se a génese e o decorrer de uma inundação são matérias cientificamente bem conhecidas e modeladas, como justificar a contínua sequência de eventos desastrosos, de maior ou menor gravidade, ano após ano? Com efeito, a ocorrência de inundações, à semelhança do que ocorre com outros perigos naturais, converte-se com demasiada frequência em desastre aquando da sobreposição do perigo com um dado contexto geográfico e social (Alexander, 1993). Um pouco por todo o globo, e também em Portugal, esse contexto tem-se traduzido por processos de forte urbanização (Gaspar, 2005; Tavares *et al.*, 2012), acompanhados frequentemente por desenraizamento das populações e perda da memória sobre o "comportamento" dos cursos de água em situação de cheia (Botzen *et al.*, 2009; Burningham *et al.*, 2008; Correia *et al.*, 1998; Figueiredo *et al.*, 2009; Smith e Tobin, 1979).

Para além das dinâmicas geográficas e sociais causadoras de maior exposição e vulnerabilidade, o próprio processo físico de inundação é marcado pela difícil previsibilidade de vários dos fatores causadores de inundação. Refira-se, por exemplo, a reduzida capacidade de prever temporal e espacialmente a ocorrência de eventos de precipitação concentrada de curta duração (Ramos e Reis, 2001), a difícil previsão da componente subterrânea do ciclo hidrológico (Paiva *et al.*, 2012; Paiva, 2015) ou a quantificação dos efeitos dos incêndios ao nível dos caudais líquidos e sólidos (Nunes e Lourenço, 2013).

Adicionalmente, os decisores e os modeladores dos processos de cheia e inundação, e respetivos impactos, devem ainda lidar com as incertezas introduzidas pelas evidências e cenários num quadro de mudança climática (Field *et al.*, 2014; Stocker *et al.*, 2013).

Os dados apresentados no último *Global Assessment Report* (GAR) (UNISDR, 2015a) salientam a relevância das cheias e inundações como processo causador de elevadas perdas no globo. Com efeito, de um total de perdas anuais médias estimadas em 314 mil milhões de dólares devidas a terramotos, maremotos, tempestades tropicais e cheias fluviais, este último processo de perigo é responsável por cerca de 33% daquele valor (Figura 2).

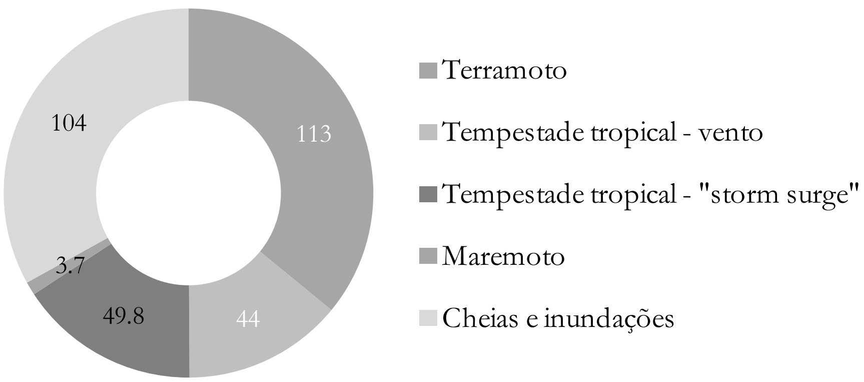

Figura 2. Estimativa de perdas anuais médias no globo, em 10^9 \$USD, segundo o GAR de 2015 (a partir de UNISDR, 2015a)

O valor de 104 mil milhões de dólares corresponde a duas vezes a despesa pública anual em saúde de todos os países do Médio Oriente e do Norte de África. A Figura 2 permite observar que as perdas médias anuais devidas a cheias e inundações são cerca de 28 vezes superiores àquelas devidas a maremotos (3,7 mil milhões \$USD) e relativamente próximas àquelas devidas a terramotos (113 mil milhões \$USD). Esta relação de forças passará porventura despercebida à população e mesmo aos decisores, abrindo questões pertinentes na área da perceção do risco e no papel dos meios de comunicação social na cobertura dos desastres naturais.

Na Europa, os impactos devidos a cheias e inundações têm registado um considerável aumento nas últimas décadas, sobretudo devido ao aumento da população, bens e atividades em áreas propensas a inundação (Barredo, 2009; Barredo, 2007; Jongman *et al.*, 2012). No período de 1980 a 2011 estão reportadas 2500 vítimas mortais e mais de 5,5 milhões de pessoas afetadas. No mesmo período, as perdas monetárias diretas, e apenas estas, ascendem a mais de 90 mil milhões de euros, em valores de 2009 (EEA, 2012).

Para Portugal, e considerando os mesmos cinco tipos de eventos representados na Figura 2, o GAR estima um valor de perdas anuais médias de 141,38 milhões de dólares, só devidas a cheias fluviais, um valor seguido de longe por aquele atribuído a terramotos (7,35 milhões de dólares).

Em termos de mortalidade e de pessoas afetadas em Portugal, apesar de o GAR basear a sua análise unicamente nos dados da base de dados EM-DAT (CRED, [s.d.]) – cujos critérios de inclusão excluem numerosas ocorrências com perdas humanas (cf. Zêzere *et al.* 2014) – as cheias são responsáveis por 24% do total de 114 vítimas mortais no período 2005-2014, considerando-se aqui todos os processos naturais causadores de mortalidade, sendo apenas ultrapassadas pelas ondas de calor.

Dados recentes coligidos aprofundadamente desde 1865 até 2010, através dos relatos noticiados pela imprensa escrita, demonstram a severidade e a frequência das ocorrências de desastres com perdas humanas relacionados com cheias e inundações em Portugal (Zêzere *et al.*, 2014). Os impactos negativos provocados pelas situações de cheia e inundação – em particular as cheias rápidas – são muito significativos em termos de perda de vidas humanas. Neste período contabilizam-se 1083 vítimas mortais e desaparecidos, 478 feridos, 40.283 desalojados e 13.372 evacuados, divididos por um total de 1621 ocorrências relacionadas com cheias e inundações. A base de dados DISASTER evidencia como apesar de o número de ocorrências registar um aumento, o número de vítimas mortais não revela uma tendência crescente. Com efeito, em trabalho apresentado recentemente (Pereira *et* *al.*, 2015a) e desenvolvido em Pereira *et al.* (2015b), dividindo a base de dados DISASTER em três períodos temporais – 1865-1934, 1935-1969 e 1970-2010 – o número de vítimas mortais observado em cada período é de 199, 219 e 72, respetivamente, representando um acentuado decréscimo no período mais recente. Atente-se ainda que na análise estatística realizada, a mortalidade associada às cheias de 25 de novembro de 1967 (522 vítimas mortais, segundo a base de dados DISASTER) não foi considerada.

Também ao nível das perdas unicamente materiais se observa a relevância deste processo de perigo, como o demonstram estudos regionais realizados a partir da base de dados DISASTER, complementados com dados de ocorrências em que houve unicamente perdas materiais, na região das Beiras (Santos *et al.*, 2014), do Baixo Mondego (Tavares *et al.*, 2013), na bacia do Rio Lis (Santos *et al.*, 2013) e na bacia do Rio Águeda (Santos e Reis, [s.d.]). Ao contrário da mortalidade, as perdas materiais analisadas nestes estudos regionais e locais mostram uma tendência crescente, em algumas áreas comprovadamente relacionada com processos de concentração e macrocefalia urbana nas sedes de concelho (e.g. Santos *et al.*, 2014, fig. 7, p. 93). Tal tendência poderá ser parcialmente justificada pelo aumento do interesse dos meios de comunicação social na reportagem dos eventos e seus impactos. A ser assim, poder-se-á estar em presença de uma maior consciência cívica e exigência perante os decisores (Kasperson *et al.*, 2001; Mendes *et al.*, 2013).

O recentemente concluído projeto CIRAC – Cartas de Inundações e de Risco em Cenários de Alterações Climáticas, da iniciativa da Associação Portuguesa de Seguradores, constitui uma iniciativa pioneira em Portugal, na avaliação quantitativa do risco de cheias e inundações (ASP, 2014). Naquele projeto, adicionalmente aos resultados em si, a abordagem metodológica inovadora na análise dos elementos expostos, sua suscetibilidade e vulnerabilidade expressos, por exemplo, na avaliação do dano médio anual para a estrutura dos edifícios e diferentes ocupações Dias *et al.* (2014), realça a importância das perdas materiais devidas a cheias e inundações.

Por esta breve introdução se compreende que a avaliação e a gestão do risco de cheias e inundações devem incluir leituras de diversas esferas do saber. O contributo das ciências da Terra não é competente para reduzir os seus impactos sem o contributo das ciências sociais, e vice-versa. Com efeito, a problemática das cheias e inundações é marcada fortemente pela intervenção humana e requer respostas a diversos níveis e escalas espaciais e temporais (Merz *et al.*, 2010) (Figura 3).

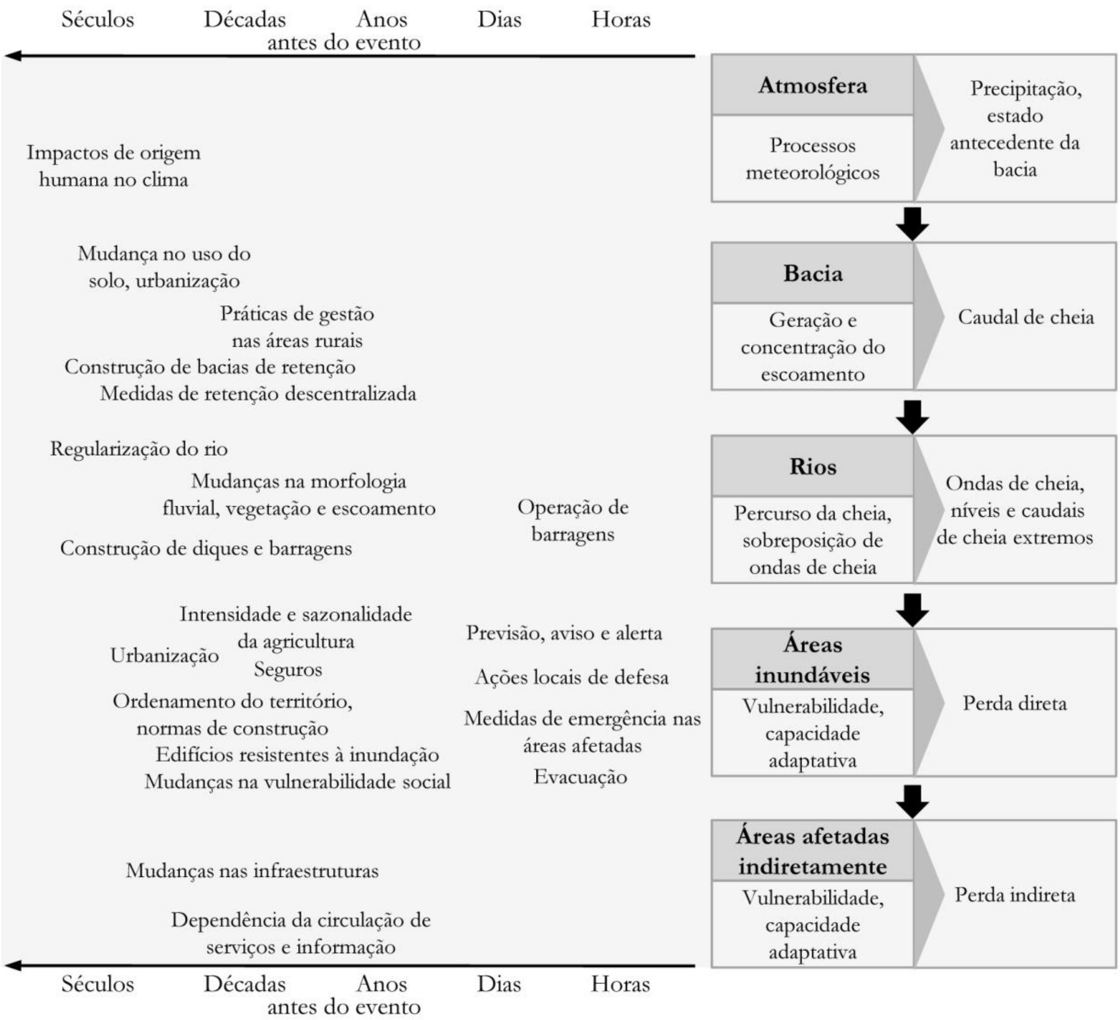

Figura 3. Capacidade da intervenção humana sobre os sistemas forçadores do risco de cheias e inundações (Merz *et al.*, 2010)

A problemática das cheias e inundações em Portugal nasce contudo, logo a montante, no campo dos conceitos. A Diretiva 2007/60/CE (UE, 2007), por exemplo, opta por uma uniformização do conceito à escala europeia. Apesar de se considerarem vários tipos de processos causadores de inundação como sejam as "cheias de origem fluvial, cheias repentinas, inundações urbanas e inundações marítimas em zonas costeiras" (cf. n.º 10), o restante documento opta unicamente pelo termo "inundação" para se referir aos efeitos da ocorrência de cada um desses processos: "riscos de inundações", "cenários de inundações" e "impactos negativos das inundações", por exemplo. A língua Portuguesa, ao contrário da Inglesa, distingue os termos, pelo que a expressão "cheia de origem fluvial" representa uma redundância.

De certo modo, a adoção do termo "inundação" como aglutinador da diversidade de processos de génese de áreas inundadas está também patente no Decreto-Lei n.º 115, de 22 de outubro, que transpõe a Diretiva 2007/60/CE para o direito Português. Não é nesse documento apresentada uma definição de cheia mas unicamente a seguinte definição de inundação: "a cobertura temporária por água de uma parcela do terreno fora do leito normal, resultante de cheias provocadas por fenómenos naturais como a precipitação, incrementando o caudal dos rios, torrentes de montanha e cursos de água efémeros correspondendo estas a cheias fluviais, ou de sobrelevação do nível das águas do mar nas zonas costeiras" (alínea b) do n.º 1 do art.º 2.º). Constata-se pela definição que o conceito de cheia está implícito enquanto processo físico causador de inundação, sendo contudo simplificado para o termo "inundação" quando o documento se refere ao seu risco e à respetiva gestão.

Em 2009, o lançamento do "Guia Metodológico para a Produção de Cartografia de Risco e para a Criação de Sistemas de Informação Geográfica (SIG) de Base Municipal" (Julião *et al.*, 2009) consistiu num assinalável esforço de clarificação terminológica para as Ciências do Risco – sobretudo riscos naturais, tecnológicos e ambientais – que se considera atual. A Tabela I apresenta os principais conceitos expressos no guia e utilizados nesta dissertação.

A definição de perigosidade compreende assim a predisposição para a ocorrência do processo natural – isto é, do perigo – ao qual se atribui uma dada severidade, a ocorrer numa dada área e com um determinado intervalo de recorrência.

Tabela I. Conceitos relevantes na esfera da avaliação do risco (Julião *et al.*, 2009)

Conceito	Definição
Perigo (*hazard*)	Processo (ou ação) natural, tecnológico ou misto suscetível de produzir perdas e danos identificados.
Severidade *(severity)*	Capacidade do processo ou ação para [causar] danos em função da sua magnitude, intensidade, grau, velocidade ou outro parâmetro que expresse o seu potencial destruidor.
Suscetibilidade *(susceptibility)*	Incidência espacial do perigo. Representa a propensão para uma área ser afetada por um determinado perigo (…), sendo avaliada através dos fatores de predisposição para a ocorrência (…) não contemplando o seu período de retorno (…).
Perigosidade ou probabilidade do perigo *(probability of the hazard)*	Probabilidade de ocorrência de um processo ou ação (…) com potencial destruidor, com uma determinada severidade, numa dada área e num dado período de tempo.
Exposição (E), Elementos expostos, Elementos em risco *(exposure, exposed elements, elements at risk)*	População, propriedades, estruturas, infraestruturas, atividades económicas, etc., expostos (potencialmente afetáveis) a um processo perigoso natural, tecnológico ou misto, num determinado território.
Vulnerabilidade (V) (*vulnerability*)	Grau de perda de um elemento ou conjunto de elementos expostos, em resultado da ocorrência de um processo (ou ação) natural, tecnológico ou misto de determinada severidade. Expressa numa escala de 0 (sem perda) a 1 (perda total).
Consequência ou Dano Potencial (C) *(consequence / potential loss)*	Prejuízo ou perda expectável num elemento ou conjunto de elementos expostos, em resultado do impacto de um processo (ou ação) perigoso natural, tecnológico ou misto, de determinada severidade.
Risco (R) *(risk)*	Probabilidade de ocorrência de um processo (ou ação) perigoso e respetiva estimativa das suas consequências sobre pessoas, bens ou ambiente, expressas em danos corporais e/ou prejuízos materiais e funcionais, diretos ou indiretos. (R = P*C).

Quanto ao conceito de cheia e inundação, recorre-se à definição patente no mesmo guia (Julião *et al.*, 2009) e referente aos processos de: cheia, que consiste no transbordo de um curso de água relativamente ao seu leito menor; subida da toalha freática acima da superfície topográfica; inundação devida a sobrecarga dos sistemas de drenagem artificiais. Esta ressalva quanto ao domínio de aplicação do conceito deve-se ao facto de o guia incluir outras definições de inundação – concretamente, por *tsunami* (ou maremoto) e por galgamento costeiro – que não têm enquadramento na presente dissertação. Assim, inundação é entendida como "um fenómeno hidrológico extremo, de frequência variável, natural ou induzido pela ação humana, que consiste na submersão de terrenos usualmente emersos" (Julião *et al.*, 2009:54).

3 Governação do risco de inundações

Transversalmente a outras esferas da vida que não unicamente aquelas relacionadas aos riscos naturais, a governação pode ser entendida como o conjunto de estruturas e processos organizados em função de uma tomada de decisão coletiva, envolvendo intervenientes governamentais e não-governamentais (Neye e Donahue, 2000).

Nos contextos de investigação científica e de ação política – como por exemplo em instituições globais como o Gabinete das Nações Unidas para a Redução de Desastres (UNISDR) ou o Banco Mundial (e.g. Jha *et al.*, 2012), bem como no setor privado – com destaque para a atividade seguradora (e.g. Kron, 2002) – procuram-se crescentemente soluções e modelos de governação do risco (Aven e Renn, 2010; Philipp *et al.*, 2013) que conduzam à convivência com os impactos associados às cheias e inundações (Schumann, 2011) através da conjugação de conceitos transdisciplinares como resiliência, redução, mitigação, adaptação e transferência de risco.

A necessidade de encontrar modelos de governação do risco constitui uma das prioridades de ação expressas no novo quadro de ação pós-Hyogo, para o período 2015-2030, saído da Terceira Conferência Mundial para a Redução do Risco de Catástrofes, realizada entre 14 e 18 de março de 2015 em Sendai, Japão: "strengthening disaster risk governance to manage disaster risk" (UNISDR, 2015b:9), exigindo uma ação que atravesse todos os sectores da governação a todas as escalas de atuação.

O modelo apresentado na Figura 4 traduz um refinamento relativamente ao modelo de governação proposto em 2005 pelo *International Risk Governance Council* (IRGC, 2005, 2008). Relativamente a esse modelo, o atual enfatiza a ideia de ciclicidade do processo desde uma fase de pré-avaliação e definição do âmbito da governação, passando pela caracterização e avaliação do risco, a partir das quais se definem e implementam as estratégias de gestão. Frequentemente se confunde gestão com governação do risco. A primeira é contudo, unicamente, uma das fases – fulcral, certamente – de todo o processo de governação (Klinke e Renn, 2012). Adicionalmente, este refinamento do modelo reforça a noção de que todo o processo assenta em três pilares expressivos da capacidade institucional, da atribuição de recursos financeiros e técnicos e de recursos humanos e capital social.

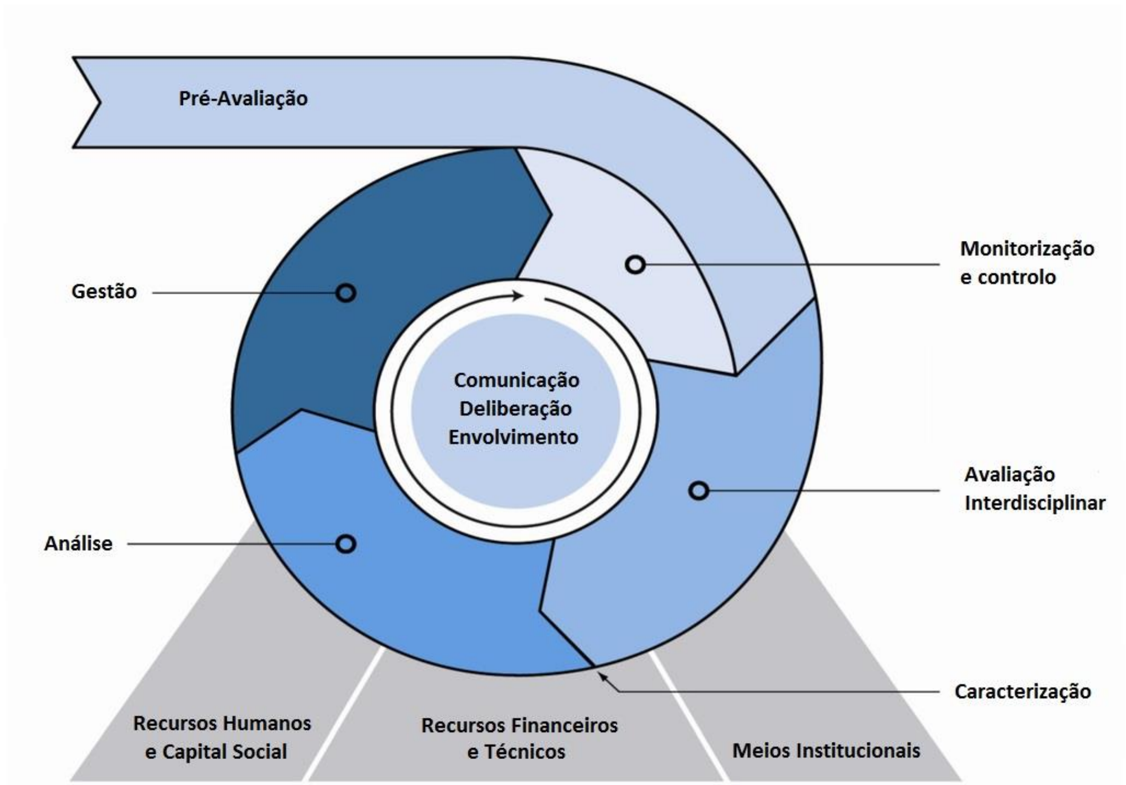

Figura 4. Modelo de governação do risco (Klinke e Renn, 2012)

Com efeito, um processo de governação na área dos riscos naturais e tecnológicos não pode deixar de incluir o envolvimento da sociedade civil nos processos de deliberação. Os cidadãos e a sociedade civil organizada estão expostos aos riscos, segundo diferentes conceções e perceções do risco (Mendes *et al.*, 2011), sendo para a sua segurança e bem-estar que o processo de governação existe. Ademais, dado que nem sempre o desastre é iminente ou ocorrente, as decisões a tomar em fase de gestão do risco podem ser origem de competição e conflitos entre as partes envolvidas, no decorrer das suas atividades quotidianas (Beck, 1992), por exemplo, pela imposição de restrições ou definição de acesso discriminatório a recursos.

Vários níveis de interação podem ser identificados num processo de envolvimento em que os interesses e as linguagens são diferentes. Por exemplo, a interação entre os intervenientes que, de um modo ou outro agravam situações de risco, e aqueles que são afetados; assim como a interação entre os intervenientes que produzem conhecimento e aqueles que o utilizarão na fase de gestão do risco (Sapountzaki *et al.*, 2011). Estas interações deverão ser contempladas através de contextos institucionais e normativos adequados, de forma a se gerar um bom nível de entendimento das necessidades e constrangimentos, e a melhor forma de os incluir em processos de decisão (Weichselgartner e Kasperson, 2010).

Nos últimos anos, a gestão do risco de eventos extremos, entre os quais os de cheias e inundações, tem colocado ênfase no aumento da resiliência como fator fulcral para a redução das perdas (Cashman, 2011; RSSPC, 2014). Segundo a Estratégia Internacional para a Redução do Risco de Catástrofes (ISDR), resiliência é a "capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure" (Nações Unidas, 2005). Como se observa, as pontes entre este conceito e o de governação do risco são notórias. Para aquele fim, no decorrer do ciclo de governação do risco de cheias e inundações, realça-se a associação entre conhecimento e consciencialização sobre o risco como a base para a construção de uma comunidade resiliente a cheias e inundações (Schelfaut *et al.*, 2011).

Atualmente, em Portugal, um modelo de governação do risco de cheias e inundações deverá considerar a já mencionada legislação emanada da Diretiva 2007/60/CE, do Parlamento Europeu e do Conselho, de 23 de Outubro, relativa à avaliação e gestão dos riscos de inundações. Este documento e a transposição concretizada através do Decreto-Lei n.º 115/2010 "aprova o quadro para a avaliação e gestão dos riscos de inundações, com o objetivo de reduzir as suas consequências prejudiciais". Com efeito, a transposição da referida diretiva marca o início de uma nova atitude perante a gestão do risco de cheias e inundações em Portugal, assente num instrumento de planeamento específico – os planos de gestão dos riscos de inundações (PGRI). Nesta fase crucial da sua implementação importa estudar estratégias de avaliação e gestão do risco que melhor lidem com os conceitos de complexidade, incerteza e ambiguidade, adotando modelos de gestão "risk-based, precaution-based and discourse-based" (Klinke e Renn, 2002). Quanto à atual legislação relativa à gestão do risco de cheias e inundações, a transposição da diretiva pode de facto permitir uma maior atuação da geografia humana e social, bem como de outros campos das ciências sociais, nas matérias de preparação, mitigação, compreensão da vulnerabilidade e da resiliência dos indivíduos e comunidades, e utilização desse conhecimento para melhor definição das estratégias de gestão, matérias a que se dedica a última parte dos resultados apresentados nesta dissertação.

4 Avaliação da suscetibilidade e da perigosidade a cheias e inundações

As metodologias de avaliação da suscetibilidade e da perigosidade a cheias e inundações testemunham uma grande riqueza e diversidade de conhecimentos aplicados. Díez Herrero *et al.* (2008) e Díez Herrero (2002) propõem a sua classificação segundo três grupos principais de métodos que avaliam a "perigosidade a inundações ou inundabilidade[1]":

- métodos históricos e paleo-hidrológicos;
- métodos geológico-geomorfológicos;
- métodos hidrológicos e hidráulicos.

Para além destes grupos principais, Díez Herrero (2002) identifica métodos de base botânica e ecológica recorrendo à dendrogeomorfologia e à liquenometria, que ainda se encontram em fase de desenvolvimento.

Outra entidade com relevante trabalho realizado na área da avaliação de áreas inundáveis é a Direção Regional do Ambiente de *Provence-Alpes-Côte d'Azur*. Em Mathieu *et al.* (2007) são sintetizados de um modo claro os diferentes métodos que considera existirem, assim agrupados: abordagem hidrogeomorfológica; estudos históricos; modelação hidráulica.

No essencial, as duas classificações são semelhantes, enraizadas em três áreas do conhecimento de natureza distinta que se podem definir, de um modo simplificado, como as ciências naturais, as ciências exatas e as ciências históricas.

[1] O termo "inundabilidade" não é usado em Portugal. Contudo, o termo parece traduzir essencialmente a propensão para a ocorrência de inundação, facto pelo qual o termo se aproximaria mais do conceito de suscetibilidade que do conceito de perigosidade.

A Figura 5, construída a partir do esquema original apresentado em Díez Herrero *et al.* (2008), descreve os principais métodos de análise da perigosidade a cheias e inundações, pormenorizando as técnicas inerentes a cada grupo, assim como as relações que se estabelecem entre eles, tendo por objetivo final a produção de cartografia de perigosidade. Uma análise a esta figura permite verificar a diversidade de relações internas em cada método e de relações entre os diferentes métodos, sendo que cada um é composto por diversas técnicas e metodologias de trabalho. Verifica-se que os métodos botânicos apenas permitem a produção de cartografia de perigosidade quando combinados com os métodos históricos. Pelo contrário, outros métodos mostram maior autonomia metodológica e alcançam isoladamente o objetivo último de cartografia de perigosidade de inundações, que são os métodos históricos e métodos geomorfológicos.

Neste esquema, a modelação hidráulica é entendida não como um método independente mas como uma técnica que utiliza o principal produto da modelação hidrológica – a estimação de caudais de ponta de cheia – o que permite concluir que a modelação hidráulica sem a modelação hidrológica, ou vice-versa, por si sós não permitem definir áreas de perigosidade a cheias e inundações.

A Figura 5 ilustra portanto a existência de ligações próximas entre famílias de métodos, não sendo os mesmos estanques, mas estabelecendo-se entre eles uma intrincada rede de conexões de técnicas que se partilham. Algumas técnicas específicas podem ser ambiguamente enquadradas em mais do que um método. A datação de sedimentos por luminescência aplicada ao estudo das cheias (Duller, 2004) por exemplo, não se enquadra claramente nos métodos geomorfológicos, motivo pelo qual alguns autores consideram a existência de um método unicamente geológico, como expresso em Díez Herrero (2002). Um outro exemplo relaciona-se com a aplicação da deteção remota na avaliação da suscetibilidade e da perigosidade: alguns autores como Benito e Hudson (2010) associam-na a ferramentas do método geomorfológico; porém não poderá a deteção remota constituir um registo histórico – por exemplo, uma imagem de satélite da década de 1970 – utilizado por si só, ou servindo de calibração a um modelo hidráulico?

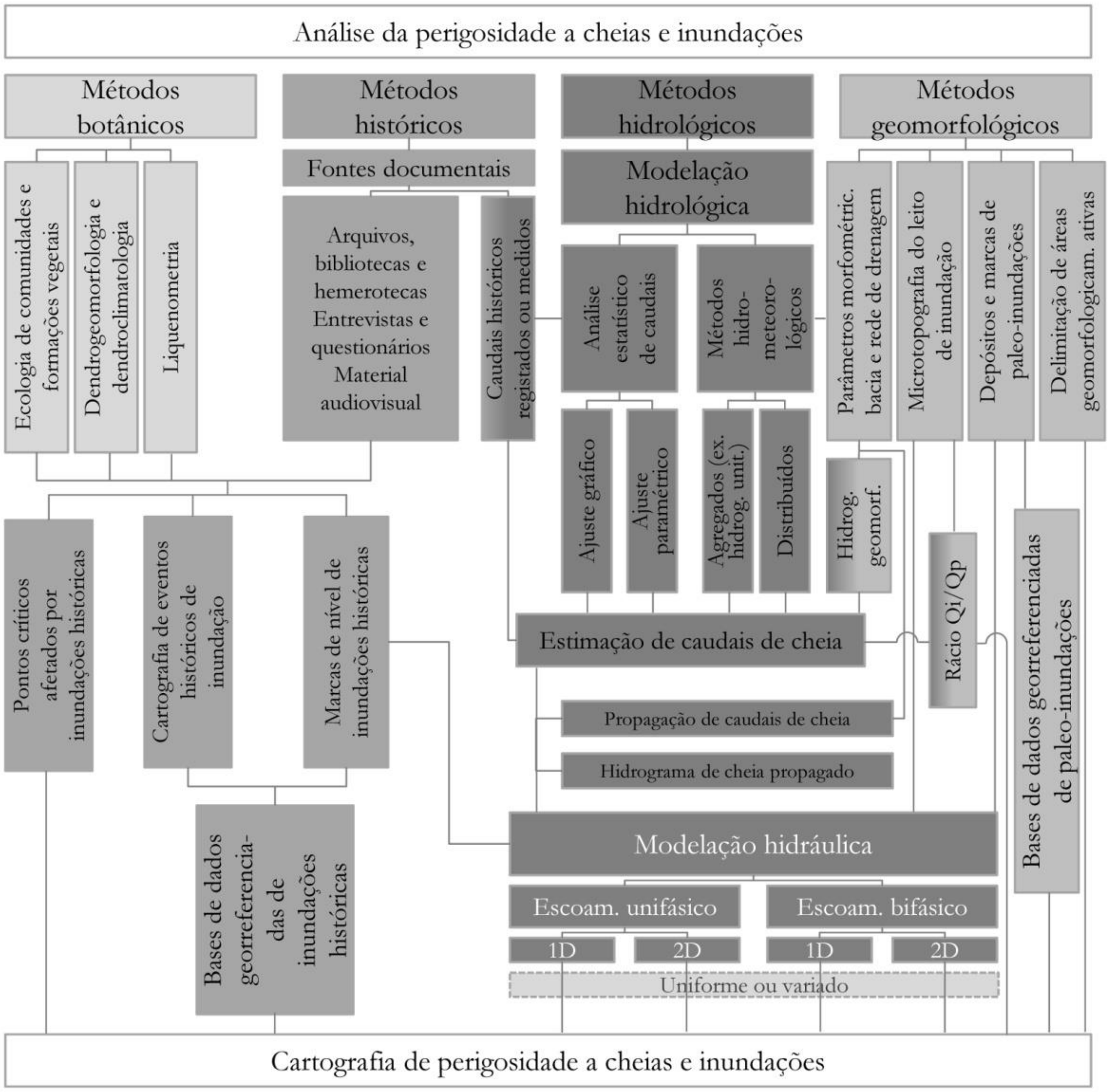

Figura 5. Métodos de avaliação da perigosidade a cheias e inundações (a partir de Díez Herrero *et al.*, 2008)

Cada método procura alcançar a cartografia de perigosidade que inclui normalmente os seguintes resultados (Díez Herrero *et al.*, 2008): mapas de áreas inundáveis, mapas de isóbatas, mapas de isótacas, mapas de pontos críticos ou obstáculos ao fluxo, perigos induzidos (deslizamentos e fluxos hiperconcentrados de sedimentos, por exemplo) e mapas de carga de sedimentos.

Segundo Wolman (1971) um mapa de perigosidade pode incluir a seguinte informação: área inundável classificada pelo respetivo intervalo de recorrência, altura da área inundada e velocidade do escoamento.

Nas secções que se seguem descrevem-se os métodos de avaliação da suscetibilidade e perigosidade a cheias e inundações, recorrendo à classificação patente na figura extraída de Díez Herrero *et al.* (2008), segundo a seguinte denominação: métodos geomorfológicos, métodos hidrológicos e hidráulicos e métodos históricos.

4.1 Métodos geomorfológicos

Os métodos geomorfológicos assentam a avaliação da perigosidade a cheias e inundações no princípio do atualismo (Hutton, 1785) que defende que "o presente é a chave do passado", e que consiste ainda hoje num dos princípios básicos do raciocínio geológico. Recorrendo ao conhecimento geomorfológico e geológico, este método está apto a analisar as cheias passadas a diferentes escalas temporais, desde há milhares de anos atrás até aos nossos tempos.

A geologia – e em particular a sedimentologia – desempenha um papel importante nos métodos geomorfológicos ao nível da caracterização dos depósitos, principalmente quanto à interpretação da sua génese, localização e datação, bem como ao estudo da sua cor, granulometria e composição.

Quanto à geomorfologia, Benito e Hudson (2010) abordam a sua aplicação na avaliação da perigosidade segundo duas escalas de análise:

- a escala da bacia de drenagem;
- a escala da planície aluvial.

4.1.1 Escala da bacia de drenagem

À escala da bacia hidrográfica, a abordagem geomorfológica procura relacionar as características morfométricas da bacia de drenagem com um determinado hidrograma de cheia, isto é, com um determinado comportamento hidrológico da bacia. Baker (1976) e Horton (1945) apresentam estudos desenvolvidos neste sentido, identificando os principais fatores geográficos que afetam a geração de escoamento e, consequentemente, das cheias: morfometria da rede de drenagem; infiltração da água no solo, em especial nas vertentes; geologia (estrutura e tectónica) e a hidrogeologia; erodibilidade do solo; uso do solo (rugosidade, impermeabilização, cobertura vegetal); e clima, de onde se salienta (i) a precipitação, quer expressa em períodos temporais maiores ou em valores médios, como por exemplo a precipitação média anual, quer relativa a períodos temporais curtos, como por exemplo a precipitação máxima anual em 24 horas e a intensidade da precipitação, e (ii) a circulação geral da atmosfera.

A abordagem do comportamento das situações de cheia a esta escala assenta no facto de que o desenvolvimento da rede de drenagem é dependente de controlo geológico, geomorfológico e hidroclimatológico. Uma das aplicações desta dependência são as expressões que definem o caudal de ponta de cheia através de funções potenciais do tipo $y=ax^b$, sendo y o caudal de ponta de cheia, a e b parâmetros que dependem da região e do período de retorno considerado, e x a área da bacia.

Outra forma de desenvolvimento da abordagem morfométrica é a definição de expressões empíricas que definem o caudal de ponta de cheia através da sua relação com a densidade e forma da rede de drenagem e com outros parâmetros morfométricos, como o comprimento da linha de água principal, a forma da bacia e o relevo. A fiabilidade da extrapolação destas fórmulas para outras regiões é muito reduzida. Uma das razões é a de que a atual rede de drenagem pode resultar de um tempo passado em que as condições climáticas fossem diferentes das atuais – c.f. Patton (1988) citado por Benito e Hudson (2010). Finalmente, outro produto desta abordagem é o g*eomorphological unit hydrograph* (Gupta *et al.*, 1980; Valdés *et al.*, 1979) que procura relacionar o hidrograma unitário instantâneo (HUI) de uma dada bacia com a geometria da rede de drenagem. A relação estabelece-se entre as características da rede de drenagem – deduzidas da hierarquia fluvial de Strahler (1957) e das "leis das redes de drenagem" de Horton (1945) – de modo a estimar variáveis como o caudal de ponta e o tempo para a ponta de cheia (Benito e Hudson, 2010).

4.1.2 Escala da planície aluvial

À escala da planície aluvial, os métodos geomorfológicos baseiam a delimitação das áreas de perigosidade "na identificação das áreas geomorfologicamente ativas no fundo do vale" (Díez Herrero *et al.*, 2008).

Mathieu *et al.* (2007) assumem a existência de três tipos de leito – leito menor, médio e maior – separados por taludes erosivos mais ou menos bem identificáveis na morfologia do plaino, com características sedimentológicas individualizadas, aos quais se podem atribuir diferentes classes de suscetibilidade (Figura 6).

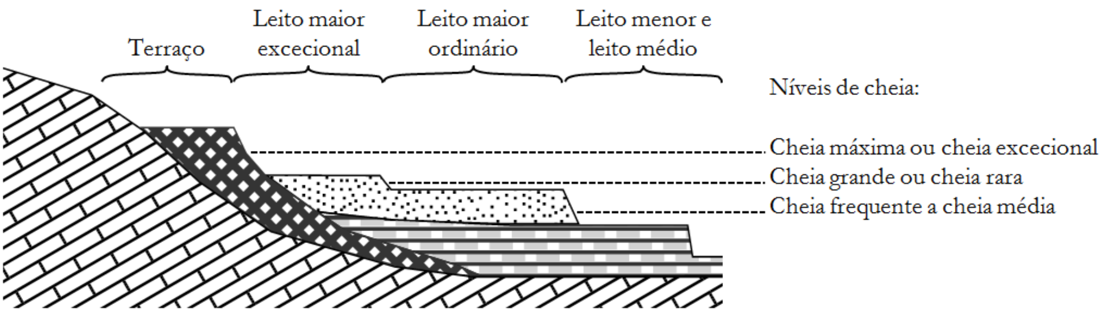

Figura 6. Tipos de leito fluvial (Mathieu *et al.,* 2007)

A esta escala, a definição da área inundável baseia-se na interpretação de indícios de inundação, como sejam: formas de erosão e deposição[2] relacionadas com a inundação; condições de drenagem do solo, seu desenvolvimento e estratificação;

[2] Distinguem-se depósitos do canal (*channel deposits*) e depósitos da planície aluvial (*bank and overbank deposits*). É igualmente possível identificar-se a migração do canal.

sedimentos e outros registos epigráficos na vegetação e nas estruturas edificadas; vegetação ripária indicativa de adaptação a humidade no solo, a alturas de água elevadas e a frequentes episódios de submersão.

Nesta tarefa, a abordagem geomorfológica recorre a diversas fontes tais como fotografia aérea, deteção remota, mapas geomorfológicos, trabalho de campo e interpretação de Modelos Digitais de Terreno (MDT), preferencialmente de alta resolução (LiDAR, ALS, etc.), beneficiando assim em grande medida dos avanços recentes no campo das tecnologias de informação geográfica e de datação, no seu contributo para uma maior fiabilidade dos resultados (Benito e Hudson, 2010). Quanto aos métodos de datação, referem-se (i) as datações de radiocarbono de sedimentos aluvionares, (ii) a datação pela técnica de luminescência opticamente estimulada (OSL) (Duller, 2004), (iii) e a datação por SAR (*single-aliquot regenerative-dose*).

Benito e Hudson (2010) abordam a aplicação do método geomorfológico à escala da planície aluvial segundo os três sectores de bacia: montante, intermédio e jusante. Segundo os autores, diferentes processos de cheia resultam em diferentes morfologias de planície aluvial. Isto é evidente quando se analisam diferentes sectores de um curso de água – estreito e de forte declive longitudinal a montante, e gradualmente alargado e de menor declive à medida que se encaminha para o nível de base. A diferenciação do leito nestes três sectores relaciona-se não apenas com o caudal associado a cada uma das formas erosivas, mas também com o período de recorrência da inundação e a velocidade, conferindo dados adicionais à avaliação da perigosidade. Esta relação contudo, necessita da aplicação de métodos hidrológicos e hidráulicos ou históricos para melhor compreensão da dimensão temporal dos processos.

Segundo Mathieu *et al.* (2007) o método hidrogeomorfológico apresenta as seguintes mais-valias:

- produz cartografia de pormenor e exaustiva que cobre toda a área potencialmente inundável, seguindo portanto uma análise integrada do sistema drenante;
- apoia-se em elementos geomorfológicos visíveis e indiscutíveis que sustentam a avaliação da suscetibilidade - nalguns casos e para alguns autores, também da perigosidade - à ocorrência de cheias no futuro. Para além da classificação da suscetibilidade pelos vários níveis da planície aluvial, o método permite a compreensão da dinâmica fluvial (zonas de erosão, acreção, de maior velocidade, etc.);
- identifica as zonas sujeitas a cheias frequentes, raras e excecionais, e as zonas que nunca serão inundadas, com vantagens para a prática do ordenamento do território;
- é de fácil aplicação, conseguindo-se obter resultados em pouco tempo e com menor custo relativamente a outros métodos.

Segundo os mesmos autores as limitações do método geomorfológico são:

- sendo um método naturalista, com enfoque na observação de campo, fornece apenas informações qualitativas e não quantitativas como a altura da cheia ou a velocidade do escoamento;
- identifica mas sem quantificar os efeitos negativos das intervenções humanas sobre a bacia e a planície aluvial. Por outro lado, o método hidrogeomorfológico não está apto a avaliar os efeitos positivos que algumas intervenções estruturais recentes possam ter (diques, aterros, regularização fluvial);
- o método não atribui uma probabilidade de ocorrência precisa aos diversos tipos de leito;

- quando os processos de urbanização são intensos em termos de alteração da topografia, este método tem dificuldades em ser aplicado;
- é um método que não pode ser aplicado a canais de irrigação, leitos regularizados, redes de drenagem urbanas;
- apesar de poder ser aplicado a qualquer sistema natural do Globo, ele é mais robustamente aplicável/adaptado a contextos morfológicos que produzem formas bem marcadas no terreno, como sejam os ambientes mediterrâneo e alpino.

Os métodos geomorfológicos são ainda valiosas ferramentas na tarefa de restauração das dinâmicas de cheia naturais, numa ótica de devolver a planície aluvial ao rio que é defendida em alguns instrumentos de gestão do risco de inundação, como os *Programmes d'Action pour la Prévention des Inondations* (PAPI) em França, por exemplo. Finalmente, uma referência para o estudo das cheias excecionais ou *paleofloods*, em que este método é eventualmente mais robusto – que os métodos hidrológicos e hidráulicos, por exemplo – devido à dificuldade destes últimos em obter dados de caudal fiáveis para tão longos períodos de retorno (Ballais *et al.*, 2005; Masson *et al.*, 1996).

4.2 Métodos hidrológicos e hidráulicos

Como a própria designação indica os métodos hidrológicos e hidráulicos são aplicados segundo duas componentes indissociáveis:

- componente hidrológica: estimação de caudais de ponta ou definição de hidrogramas de cheia a partir de dados meteorológicos e/ou hidrométricos;
- componente hidráulica: modelação, segundo leis físicas, do escoamento sob determinadas condições "encaixantes" – fundamentalmente, de topografia e rugosidade.

O princípio de aplicação dos métodos hidrológicos e hidráulicos "consiste em tentar reproduzir uma determinada cheia em função de um certo número de parâmetros que permitem representar de um modo simplificado a realidade complexa do terreno e do funcionamento dos cursos de água" (Mathieu *et al.*, 2007).

Segundo os mesmos autores a aplicação de métodos hidrológicos e hidráulicos segue as seguintes fases:

1 – análise dos dados hidrológicos e meteorológicos de modo a produzir um hidrograma de cheia e a estimar os caudais de ponta de cheia para vários períodos de retorno;

2 – aquisição de dados geométricos que descrevam a planície aluvial e as infraestruturas existentes; podem incluir o levantamento batimétrico do leito menor, levantamento topográfico do plaino aluvial e a descrição das estruturas hidráulicas e outras construções;

3 – análise do funcionamento hidráulico (regime de escoamento, parametrização da rugosidade, comportamento das estruturas hidráulicas como pontes, açudes, etc.);

4 – cálculo e produção cartográfica que inclui os seguintes passos, sendo que alguns podem não ser aplicados:

- construção de um modelo numérico onde se integram os dados geométricos e hidrológicos;

- simulação para diferentes eventos de cheia (estimados ou concretos/medidos);

- execução e comparação de várias simulações de forma a calibrar o modelo com os dados reais (históricos) e definição das alturas da cheia e das velocidades;

- elaboração da cartografia de zonas inundáveis.

Após a obtenção dos caudais de ponta, por análise estatística de caudais (quando disponíveis) ou por métodos de estimação hidrometeorológica, segue-se a fase de modelação hidráulica. A modelação hidráulica assenta na aplicação de leis e equações físicas que simplificam o comportamento hidráulico dos sistemas fluviais e cuja resolução permite estimar diferentes parâmetros hidráulicos, como a profundidade, a velocidade e a energia (Díez Herrero *et al.*, 2008). No programa de modelação unidimensional HEC-RAS, por exemplo, a computação do escoamento entre determinada secção transversal e a secção transversal seguinte baseia-se na resolução da equação da conservação da energia (USACE, 2002), expressa por:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

sendo Y_1 e Y_2 a profundidade do escoamento (m), Z_1 e Z_2 a cota (m), V_1 e V_2 a velocidade média (m/s), a_1 e a_2 o coeficiente de ponderação da velocidade, g a aceleração gravitacional e h_e a perda de energia calculada pela equação de Manning. A estimação da perda da energia pela equação de Manning é dada por:

$$h_e = L\overline{S_f} + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right|$$

sendo L a distância entre secções ponderada pela vazão (m), S_f a declividade da linha de energia (m/m) e C o coeficiente de contração ou expansão. Os resultados da aplicação da equação da energia são a profundidade e a velocidade do escoamento em cada ponto da secção transversal.

Para além das aplicações que modelam o escoamento a 1D, existem aplicações a 2D, 3D e aplicações que modelam o transporte de sedimentos e a morfodinâmica dos cursos de água (Tabela II). Nos sistemas naturais raramente o escoamento se faz de um modo unidirecional, principalmente quando ocorre transbordo de um canal ou leito ordinário (Díez Herrero *et al.*, 2008). Os modelos unidimensionais são também pouco eficazes na modelação do escoamento quando haja confluência de cursos de água, na modelação ao redor de estruturas hidráulicas, em contexto de meanderização pronunciada e em meio urbano. Alguns programas incorporam os dois modelos (1D e 2D) aplicando o modelo 2D quando o primeiro não é adequado.

Tabela II. Principais modelos hidráulicos (Díez Herrero *et al.*, 2008)

Modelos hidráulicos	Fluxo unidimensional: HEC-RAS, MIKE-11, WSPRO, FLDWAY, DAMBRK, etc.
	Fluxo bidimensional: MIKE-21, Guad-2D, Telemac, FLOW-2D, Sobek, Tuflow, Kalypso, etc.
	Modelos 3D: MIKE 3, Telemac 3D, FLOW 3D, AULOS, FLOTRAN, CFX, etc.
	Modelação de transporte de sedimentos e morfodinâmica dos rios (leito móvel), que podem ser modelos 1D, 2D ou 3D: DELTA, MOSEC, HEC-6, HEC-RAS v4.0, SEDIMOD, SED 2D, etc.

Na realidade o escoamento fluvial exerce-se a 3D mas a simplificação a 2D é aceitável, nos casos em que as variações verticais das componentes horizontais são pequenas e a distribuição vertical da pressão é hidrostática – Díez Herrero *et al.* (2008) suportado igualmente por Bates e De Roo (2000) e Horritt e Bates (2001). De facto, a modelação a 3D não é praticável em sistemas fluviais para extensas áreas porque implica um elevado custo financeiro e de tempo em computação, sem que os resultados sejam significativamente melhores relativamente aos modelos bidimensionais.

A discussão sobre este assunto continua na ordem do dia. O modelo de simulação hidráulica mais exequível e prático é aquele que melhor combina os seguintes fatores: dados de entrada, representação do processo – as suas leis físicas – e dados de validação do modelo (Horritt e Bates, 2001).

De facto, e como ilustra a Figura 7 elaborada em concordância com as conclusões expressas em Horritt e Bates (2001), não se obtêm bons resultados aplicando modelos robustos com dados de caudal e/ou morfológicos fracos, e vice-versa. Os modelos unidimensionais – que se baseiam na resolução das equações ou aproximações às equações de Saint Venant – têm sido usados pela sua relativa simplicidade computacional e de parametrização, mas ignoram aspetos relevantes da hidráulica fluvial em sistemas naturais. Os modelos 2D são mais completos neste aspeto, mas também mais exigentes em dados de entrada como os relativos à geometria e à rugosidade, e aos dados de validação (Horritt e Bates, 2001). A crítica no mesmo sentido e maior sinal é indicada para os modelos 3D.

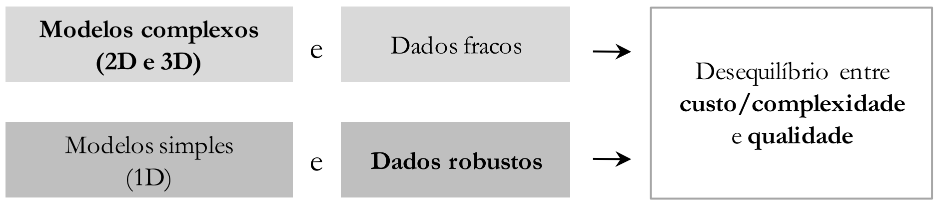

Figura 7. Desequilíbrios na combinação de diferentes graus de robustez e qualidade de modelos e dados para simulação hidráulica.

Realçando que muitos estudos de modelação estão limitados pelos dados disponíveis, parece poder-se concluir então que "it is obvious that it would be wasteful to use a complex process representation in a model that cannot be parameterized with sufficient accuracy" (Horritt e Bates, 2001). Bates e De Roo (2000), com base em resultados de um estudo realizado na Holanda, concluem também que "topography is more important than process representation for predicting inundation extent, and a relatively simple model can be used to good effect." Os mesmos autores avançam ainda que a situação atual proporciona-se a uma maior utilização dos modelos 2D porque:

- os modelos 1D são demasiadamente simplistas no tratamento do escoamento fluvial, especialmente em situação de transbordo (*overbank*);
- os modelos 3D são desnecessariamente complexos e computacionalmente intensivos;
- têm surgido técnicas recentes que colmatam as lacunas apontadas à aplicação de modelos 2D, quanto à qualidade dos dados de entrada, de parametrização e de validação como seja: obtenção de dados topográficos usando técnicas de levantamentos topográficos com tecnologia laser (LiDAR, por exemplo), permitindo construir MDT de elevada precisão e relativo baixo custo

(quando comparados com a técnica de aerofotogrametria); obtenção de dados para validação da área inundável, por exemplo, através de imagens de satélite e de radar.

Parece poder concluir-se que, no momento atual, é mais importante investir na qualidade dos dados de entrada e na validação dos modelos que na complexidade da representação dos processos.

As vantagens mais comumente indicadas da aplicação de modelos hidráulicos são (Mathieu *et al.*, 2007):

- a quantificação das alturas da inundação, das velocidades e da duração da inundação (neste caso específico, apenas se se usarem hidrogramas de cheia);
- a atribuição de probabilidades de ocorrência concretas a determinados níveis de inundação, permitindo com maior clareza a avaliação da perigosidade (não obstante as imprecisões nos dados de entrada).

Como fragilidades, os mesmos autores apontam a existência de imprecisões e/ou assunção de hipóteses simplificadoras quanto à precisão dos dados topográficos, à não consideração das modificações morfológicas ocorridas no leito menor durante a cheia nem da migração do canal sobre a planície aluvial, ao comportamento das estruturas hidráulicas, às séries de dados hidrológicos e hidrométricos utilizadas na estimação de caudais com períodos de retorno muito elevados (cheias excecionais), e à modelação do transporte sólido. Constrangimentos adicionais inerentes à aplicação destes métodos relacionam-se com (i) a necessária calibração dos modelos hidráulicos, que nem sempre é possível por falta de dados históricos, (ii) a não determinação do limite máximo da planície aluvial, dado que a morfologia fluvial não é interpretada e (iii) o facto de ser um método caro e de difícil aplicação a extensas áreas.

Comparativamente aos métodos geomorfológicos, Benito e Hudson (2010) consideram que a cartografia de perigosidade realizada por métodos hidrológicos e hidráulicos é mais dispendiosa, pela necessidade de cartografia de grande escala e pela necessidade de recolha de séries longas de precipitação e de caudal ao longo de décadas.

Finalmente, e tal como foi referido em relação aos métodos geomorfológicos, a disponibilidade cada vez maior de dados de satélite contribuirá para aumentar a confiança nos resultados dos modelos hidráulicos porque permitirá realizar melhor calibração (Horritt e Bates, 2001), mantendo-se contudo, e para essa finalidade, a necessidade de se dispor de dados de precipitação e de caudal. Uma melhor calibração significa também um contributo para a aferição de qual o nível necessário de complexidade dos modelos, de modo a garantir a melhor fiabilidade de resultados.

4.3 Métodos históricos

Segundo Mathieu *et al.* (2007) "l'analyse historique est une approche essentiellement littéraire: elle consiste à recenser toutes les données disponibles sur les inondations passées à partir de différentes sources (...)". As fontes recolhidas incluem (ver exemplos na Figura 8):

- marcas e placas relativas a eventos ocorridos no passado;
- documentação histórica, como monografias regionais, arquivos audiovisuais, de imprensa, etc.;
- questionários à população e a entidades estatais e audiovisuais.

O objetivo principal da aplicação de métodos históricos é o de reconstruir a extensão da zona inundável em eventos concretos ocorridos no passado. Havendo séries suficientemente longas de registos é possível, pela aplicação de funções probabilísticas, estimar os intervalos de recorrência de cada evento. Os registos históricos atuam frequentemente como base para definição do conceito de "crecida histórica" (Díez Herrero *et al.*, 2008).

Granja do Ulmeiro. Nível da cheia de Jan/2001

Soure. Nível da cheia de Out/2006

Mértola. Nível da cheia de Dez/1875

Figura 8. Exemplos de registos históricos de cheias e inundações.

Os mesmos autores aproximam dos métodos históricos uma abordagem a que denominam método paleohidrológico, que recorre à identificação de marcas e depósitos referentes a inundações passadas (anteriores ao período histórico ou das quais não se disponha de informação histórica[3]) passíveis de datação mediante técnicas paleontológicas, dendrocronológicas, radiométricas (^{14}C, OSL, TL, etc.) ou arqueológicas. Como se constata, estas técnicas apresentam alguma semelhança com técnicas usadas igualmente pelos métodos geomorfológicos (ou geológico-geomorfológicos na sua designação mais ampla).

[3] *Paleofloods* na designação anglo-saxónica.

Os resultados da abordagem histórica na definição de áreas inundáveis expressam-se em duas perspetivas distintas: ao nível da avaliação da suscetibilidade e da perigosidade, a reconstituição da cronologia e, quando possível, da extensão das inundações passadas; ao nível da consciencialização, pelo reavivar na população – e nas entidades com responsabilidade sobre a gestão do risco – a memória das inundações passadas, contribuindo para aumentar a sua capacidade de adaptação e prevenção face à sua exposição ao perigo (Mathieu *et al.*, 2007). Identificam-se contudo os seguintes limites de utilização: falta de registos, nos principais cursos de água, porque as pessoas e/ou a imprensa não deram relevância ou não quiseram perpetuar essa memória em marcas de cheia, e nas pequenas linhas de água, onde a presença humana é escassa ou ausente; a perda e/ou inacessibilidade aos registos; a inexatidão de alguns registos quanto a datas e extensão da área inundada.

5 Bases de dados de perdas devidas a cheias e inundações

O estudo das perdas associadas a cheias e inundações é porventura uma das áreas que reúne maior interesse entre três esferas de atores que frequentemente desenvolvem a sua atividade de um modo isolado: a comunidade científica, os promotores – quer públicos quer privados – e os cidadãos (Dieperink *et al.*, 2013). O motivo do interesse na recolha e análise de perdas é porém diverso entre os vários intervenientes, podendo-se resumir em três finalidades principais: fins puramente científicos, análise de impactos para fins de planeamento, e cálculo de prémios e indemnizações no setor segurador (Thieken *et al.*, 2009). À parte estas diferenças, existe um interesse crescente que se deve fundamentalmente à severidade e frequência das perdas causadas pelas cheias e inundações (Jha *et al.*, 2012; Merz *et al.*, 2011), acentuada por níveis de incerteza e complexidade na estimação e quantificação quer da perigosidade – e.g. Apel *et al.* (2009) – quer da vulnerabilidade e dos elementos expostos – e.g. Messner e Meyer (2005).

Deve-se realçar igualmente a importância que é atribuída ao conhecimento dos eventos desastrosos passados – quer no anterior quadro da Estratégia Internacional para a Redução do Risco de Desastres que vigorou entre 2005 e 2015 (Nações Unidas, 2005) quer no atual quadro saído da Conferência de Sendai (UNISDR, 2015b) – como pilar das ações que visam aumentar a resiliência aos desastres naturais.

As bases de dados de eventos e de perdas constituem, portanto, uma ferramenta fundamental para a avaliação da vulnerabilidade e dos elementos expostos, sendo que cada vez maior número de países dispõe de inventários de eventos e respetivas perdas e danos (cf. *Global Risk Information Platform* em www.gripweb.org).

Em Portugal, oportunamente, deu-se início ao projeto DISASTER (Zêzere *et al.*, 2014), cuja primeira finalidade consistiu em fornecer à comunidade científica e aos decisores uma base de dados de perdas e danos de natureza humana – eventos desastrosos em que se tenham registado vítimas mortais, desaparecimentos, ferimentos, desalojamentos e/ou evacuação de pessoas, independentemente do seu número – tal como registados na imprensa escrita. Com efeito, muitos outros países no contexto europeu e internacional, dispunham já de bases de dados similares há vários anos (Barnolas e Llasat, 2007; Guzzetti *et al.*, 1994; Karagiorgos *et al.*, 2013; Pielke *et al.*, 2002; Rüdiger e Stangl, 2004; Shrubsole *et al.*, 1993). A relevância da imprensa escrita para a reconstituição histórica dos eventos de cheia e inundações e seus impactos associados em contextos de intenso e rápido crescimento urbano, como é o caso da cidade de Shangai, é igualmente salientada (Du *et al.*, 2015).

A referida base de dados DISASTER vem providenciar uma leitura não apenas hidrológica e climatológica, como também de geografia humana, pelo que permite de análise temporal e espacial do desenvolvimento do território – a litoralização do País, por exemplo – e até porventura das mudanças sociais expressas nos padrões de mortalidade e de pessoas afetadas (Pereira *et al.*, 2015b).

A UNISDR publica de dois em dois anos um relatório dedicado à avaliação do risco e das estratégias correntes e tendentes no esforço global para a redução do risco de desastres – no original, "disaster risk reduction" (DRR), expressão que não é muito corrente em Portugal. Estes relatórios – os *Global Assessment Reports*, já referidos anteriormente no capítulo 2 – assentam a sua análise na informação disponibilizada pelos países membros das Nações Unidas. Um facto tem sido notável desde 2009 para 2015, que é o crescimento da informação sistematicamente recolhida e atualmente disponível, relativa a desastres: o GAR de 2009 apenas dispunha de dados para 13 países, o GAR 2011, para 22, o GAR 2013 para 56 e o GAR 2015, para 85 países (UNISDR, 2015a). Este simples dado reflete a crescente preocupação dos decisores com a gestão dos riscos naturais e tecnológicos, que por sua vez se reflete na necessidade de dispor de bases de dados de perdas, que possibilitem uma melhor avaliação do risco.

Segundo Kron *et al.* (2012), são diversos os intervenientes que se dedicam à construção, manutenção e utilização de bases de dados de perdas por cheias e inundações, de entre os quais se destacam o setor segurador, a comunidade científica, as Nações Unidas, a União Europeia, as organizações governamentais e não-governamentais, os serviços geológicos e meteorológicos e os meios de comunicação social.

Contudo, a utilização destas bases de dados requer procedimentos de verificação e uniformização (Barredo, 2009) antes que a informação possa ser adequadamente utilizada em modelos de análise de risco (Kron *et al.*, 2012). A quantificação de danos diretos, indiretos, tangíveis e intangíveis é outro desafio atual colocado à análise de vulnerabilidades e elementos expostos (Cardona *et al.*, 2012; Gall *et al.*, 2009; Jonkman *et al.*, 2008; Jonkman *et al.*, 2008).

A avaliação da vulnerabilidade a cheias e inundações pode compreender uma miríade de aspetos, desde aqueles que se relacionam com as características da inundação e do processo que lhe deu origem, até àqueles mais dificilmente quantificáveis como a preparação e a capacidade de adaptação (Messner e Meyer, 2005) (Figura 9). Neste processo, uma base de dados de perdas por cheias e inundações pode constituir um elemento de suporte valioso, consoante o detalhe e alcance dos campos da mesma, bem como do tipo de fonte selecionado.

As bases de dados podem considerar diferentes tipos de perdas, estando estas classificadas em diretas e indiretas, tangíveis e intangíveis. As duas perspetivas podem ser combináveis e bidirecionais, ou seja, pode-se por exemplo classificar uma perda como direta tangível ou intangível, assim como determinada perda pode ser classificada como tangível direta ou indireta. As perdas diretas são aquelas que ocorrem devido ao contacto físico entre a água ou materiais arrastados pelo escoamento devido à inundação e os seres vivos, propriedades ou quaisquer outros objetos. As perdas indiretas são aquelas induzidas pelas perdas diretas, isto é, sem que exista contacto direto com a inundação, pelo que podem ocorrer, no tempo ou no espaço, fora ou para além do evento (Merz *et al.*, 2004).

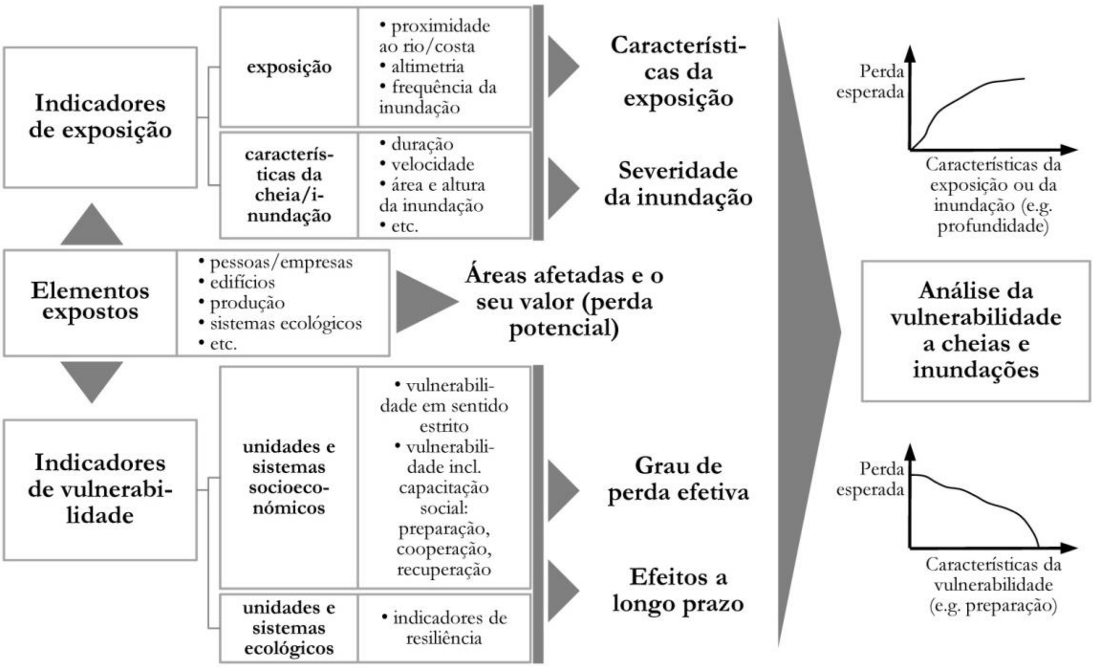

Figura 9. Possíveis indicadores para a análise de vulnerabilidade a inundações (Messner e Meyer, 2005)

A Figura 10 descreve detalhadamente algumas perdas tangíveis – diretas e indiretas – segundo a dimensão temporal e segundo a relação espacial com a área efetivamente inundada num dado evento (Thieken *et al.*, 2009).

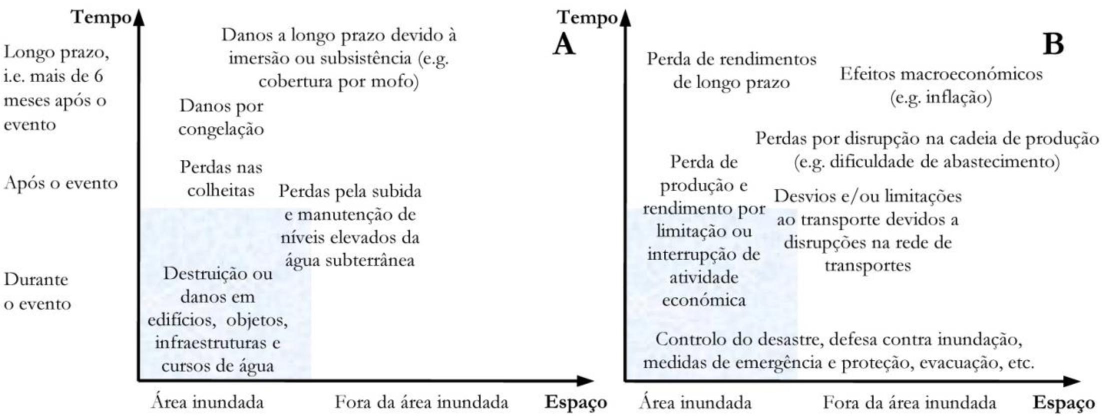

Figura 10. Tipos de perdas tangíveis diretas (A) e indiretas (B) (Thieken *et al.*, 2009)

As perdas diretas são frequentemente classificadas segundo o tipo de bem ou função que é afetada: áreas residenciais; setor comercial e industrial e serviços públicos; setor agrícola; e setor dos transportes (Thieken *et al.*, 2009).

As perdas indiretas incluem dimensões muito diversas e difíceis de quantificar: por exemplo, as consequências no turismo, na mobilidade de pessoas e bens, na cadeia produtiva, na regeneração ambiental, nos custos para a saúde, nos indicadores macroeconómicos como a inflação e o desemprego, na ação dos serviços de proteção civil, etc. (Messner e Meyer, 2005). Sendo difícil, a estimação destas perdas é passível de ser realizada. Uma via para isso é a aplicação de modelos sistémicos económicos de entrada e saída, para a estimação de efeitos económicos estruturais de inundações de grande escala (Bočkarjova *et al.*, 2007). A menor escala, pode-se referir igualmente um estudo holandês que estima perdas económicas indiretas e perda de vidas (Jonkman *et al.*, 2008).

As perdas intangíveis não constam da maioria de bases de dados de perdas de um modo economicamente mesurável, senão de um modo descritivo. Os mesmos autores propõem a seguinte classificação (Tabela III).

Tabela III. Classificação de perdas devidas a cheias e inundações (Jonkman *et al.*, 2008)

	Tangíveis e com valor monetário	**Intangíveis e sem um valor monetário atribuível**
Diretas	Habitações Perdas em património imobilizado e produtos comercializáveis Interrupção da atividade económica (na área inundada) Veículos Terras agrícolas e gado Estradas e outras infraestruturas logísticas e de comunicação Operações de evacuação e salvamento Reconstrução de defesas contra inundações Custos de limpeza e desobstrução	Morte Ferimento Inconveniências e danos morais Serviços e comunicações Perdas de património histórico e cultural Impactos ambientais
Indiretas	Perdas para a atividade económica fora da área inundada Ajustamentos na produção e nos padrões de consumo Alojamento temporário das pessoas evacuadas	Disrupção societal Traumas psicológicos Falta de confiança nas autoridades públicas

Em relação à comunicação, é interessante verificar como se distingue a perda tangível na infraestrutura que realiza a comunicação, e a perda intangível expressa na impossibilidade de estabelecer comunicação (Tabela III).

As bases de dados de perdas constituem um elemento fundamental para a corrida de modelos de avaliação de perdas, sendo que a qualidade das mesmas tem uma significativa influência nos resultados obtidos (Jongman *et al.*, 2012; Merz *et al.*, 2013).

A comunidade científica debate-se atualmente com a complexidade inerente à avaliação, ou estimação, de perdas causadas por cheias e inundações (Penning-Rowsell, 2015). Com efeito, a qualidade da estimação de perdas – realizada frequentemente através de curvas de profundidade-dano – parece depender muito mais de uma correta avaliação dos elementos em risco que da avaliação da extensão e profundidade da inundação (de Moel e Aerts, 2011).

6 Componentes da gestão do risco

Frequentemente, classificam-se as medidas de gestão do risco de cheias e inundações em dois grupos principais: medidas estruturais e não estruturais. De entre as medidas estruturais salientam-se as modificações das condições de escoamento da bacia de drenagem, a construção de estruturas de proteção e de desvio do escoamento tais como barragens, diques, canais de diversão ou sistemas de bombagem, que podem ser projetadas (i) a diferentes escalas geográficas de atuação – por exemplo, opção por uma grande barragem ou por várias pequenas barragens ou bacias de retenção –, (ii) de acordo com práticas locais tradicionais ou práticas "importadas" mais ou menos ecológicas – por exemplo, a opção por margens de canais de escoamento em betão ou em vegetação natural. Quanto às medidas não-estruturais, o leque de soluções apresenta uma maior diversidade, destacando-se as seguintes:

- restrição na ocupação de áreas de risco através de instrumentos de gestão territorial;
- deslocalização de infraestruturas, equipamentos e áreas residenciais para áreas de segurança ou de risco tolerável;
- devolução da planície aluvial ao rio segundo o princípio de "make space for water";
- mitigação de perdas através da atividade seguradora;
- melhoria do conhecimento disponível e métodos de apoio à tomada de decisão, que enfatizam a capacidade de modelação dos processos de risco, quer ao nível da perigosidade, quer ao nível da vulnerabilidade e elementos expostos;
- sistemas compensatórios solidários para as áreas que aceitam mais risco em benefício de áreas mais vulneráveis;
- sistemas de aviso e alerta, e ações de informação e sensibilização;
- participação pública nos processos de gestão.

O leque de medidas que são adotadas, quer formalmente quer informalmente, surge por vezes na sequência da ocorrência de um evento desastroso de tal severidade que torna intolerável a situação anterior ao impacto (Figura 11). Na Europa, as cheias de Agosto de 2002, que afetaram sobretudo os países da Europa Central, foram o facto que levou a um maior interesse pela análise de perdas, bem como, de um modo geral, pela procura de um novo paradigma, formal, de gestão do risco.

Contudo e desejavelmente, a mudança no sentido de reduzir ou mitigar o risco deveria surgir pelo conhecimento e consciencialização dos potenciais impactos associados a um evento desastroso, antes que o mesmo aconteça (Birkmann *et al.*, 2010).

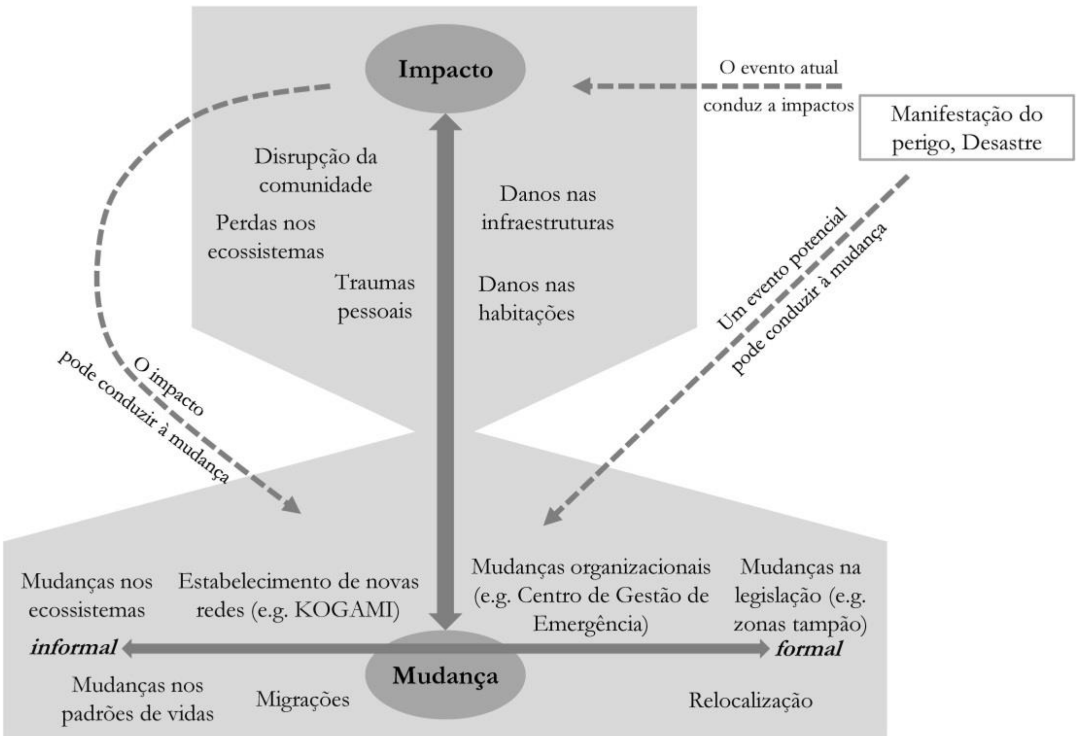

Figura 11. Forçadores e tipos de mudança em gestão do risco (Birkmann *et al.*, 2010).

De entre as mudanças formais identificadas em Birkmann *et al.* (2010), a legislação portuguesa passada e atual apresenta já um percurso que demonstra a relevância do tema e a necessidade de o gerir. Com efeito, previamente à Diretiva 2007/60/CE, a legislação portuguesa inclui já um conjunto de regimes legais versando sobre a problemática das inundações, que não serão revogados com aquele documento nem com a sua transposição pelo Decreto-Lei n. 115/2010, mas exigirão um esforço de adequada articulação e compatibilização.

Destaca-se o regime do Domínio Público Hídrico (Decreto-Lei n.º 468/71, de 5 de Novembro, alterado pelos Decretos-Lei n^{os} 53/74, de 15 de Fevereiro, e 89/87, de 26 de Fevereiro, e pela Lei n.º 16/2003, de 4 de Junho), que prevê a "figura das zonas adjacentes, determinando a sujeição a restrições de utilidade pública dos terrenos considerados como ameaçados pelo mar ou pelas cheias."

A Reserva Ecológica Nacional, Decreto-Lei n.º 166/2008, de 22 de agosto, com as alterações introduzidas pelo Decreto-Lei n.º 239/2012, de 2 de novembro, que numa perspetiva preventiva considera as zonas ameaçadas pelas cheias como áreas de risco e prevê um conjunto de restrições à sua utilização, tais como operações de loteamento, obras de urbanização, construção e ampliação, vias de comunicação, escavações e aterros e destruição do revestimento vegetal (cf. n.º 1 do artigo 20.º).

Com um carácter mais pontual, mas ainda assim relevante, o Decreto-Lei n.º 364/98, de 21 de Novembro, que determina a obrigatoriedade de os municípios com aglomerados urbanos atingidos por cheias "elaborarem cartas de zonas inundáveis abrangendo os perímetros urbanos, visando a adoção de restrições à edificação face ao risco de cheia."

Mais recentemente, a Lei da Titularidade dos Recursos Hídricos, aprovada pela Lei n.º 54/2005, de 15 de Novembro, que revoga os capítulos I e II do Decreto-Lei n.º 468/71, de 5 de Novembro, mas mantém o regime jurídico aplicável às zonas adjacentes e estabelece a possibilidade de se classificar como zona adjacente as zonas também ameaçadas pelo mar.

Finalmente, a Lei da Água, aprovada pela Lei n.º 58/2005, de 29 de Dezembro, e que vem revogar os capítulos III e IV do Decreto-Lei n.º 468/71, "estabelece, em sede de medidas de proteção contra cheias e inundações, a obrigação de nos instrumentos de planeamento dos recursos hídricos e de gestão territorial serem demarcadas as zonas inundáveis ou ameaçadas pelas cheias" e pelo mar, devendo estas ser classificadas nos termos da Lei da Titularidade dos Recursos Hídricos, ficando sujeitas às restrições previstas nesta lei.

A legislação existente destina-se essencialmente à identificação de áreas de suscetibilidade – e em alguns casos de perigosidade – e definição de restrições com o intuito de salvaguarda de pessoas, bens, acessos e valores ecológicos. Pode-se concluir que subsistia uma lacuna, que vem agora ser preenchida, encarando a gestão dos riscos de inundações nas suas diversas dimensões (biogeofísica e socioeconómica) e, o que é inédito, tendo por unidade de trabalho a bacia hidrográfica[4].

Todas estas respostas, porém, incidem sobre legislação com reflexo na distribuição de atividades e da ocupação humana sobre o território, definindo regras e condicionantes ao seu usufruto. Porventura, a Diretiva 2007/60/CE, que será alvo de uma análise mais aprofundada em um dos artigos apresentados na Parte II – Resultados, tem o potencial para abrir o leque de estratégias de redução e mitigação do risco de cheias e inundações a outros campos. O forte enfoque que é dado à participação pública e à análise custo – benefício na definição das estratégias a considerar nos planos de gestão dos riscos de inundações é disso um indício.

[4] Pode-se ler no preâmbulo do Decreto-lei n.º 115/2010 " (…) medidas de redução dos riscos de inundações previstas no presente decreto-lei, devem as mesmas ser, tanto quanto possível, coordenadas à escala das bacias hidrográficas, e devidamente articuladas com os regimes legais em vigor, considerando os vários tipos de fenómenos de inundações".

6.1 Mitigação do risco

A mitigação do risco constitui uma das esferas de atuação à disposição das políticas de gestão do risco situada na interface entre os dois prismas maiores segundo os quais se pode perspetivar a gestão: foco tecnológico e foco societal (Tavares, 2013).

Para Godschalk *et al.* (1999) a mitigação de perigos naturais consiste na tomada de ações que visam reduzir ou eliminar o risco para pessoas e bens numa escala temporal de longo prazo. Ao focalizar o âmbito das ações sobre o risco, o conceito exposto abrange as ações que visam não apenas a redução da perigosidade, mas também da vulnerabilidade e dos elementos expostos (Varnes, 1984). Esta constatação é relevante porque significa que a mitigação não atua somente sobre o processo de perigo. Por fim, os autores referem que as ações podem ser de natureza estrutural ou não-estrutural.

Das várias definições de mitigação enunciadas, todas enfatizam o objetivo de minimizar ou limitar as consequências adversas relacionadas com a ocorrência de um dado processo de perigo (UNISDR, 2009). As medidas de mitigação são por natureza medidas tomadas "in advance", ou seja, previamente à ocorrência dos processos de perigo. As medidas não estruturais são as que apresentam um leque mais diversificado de soluções, podendo consistir em educação e sensibilização, sistemas de aviso, fundos financeiros de compensação, sistemas de seguros e resseguros, e sistemas de decisão partilhada entre partes interessadas (Hansson *et al.*, 2008).

No campo das respostas sociais e institucionais ao risco de inundação na União Europeia, países como o Reino Unido, a França, a Holanda e a Alemanha percorreram já um caminho de saber adquirido pela experiência que poderá ser útil no contexto português – ver por exemplo os projetos KULTURISK (http://www.kulturisk.eu), STAR-FLOOD (http://www.starflood.eu) e FLOODsite (http://www.floodsite.net). Cashman (2011), por exemplo, apresenta um estudo realizado no condado de Bradford, Reino Unido, no qual evidencia a mudança entre uma estratégia de mitigação que enfatiza o investimento e a confiança em medidas estruturais ("structural robustness"), para uma estratégia em que esta visão coexiste com outra que privilegia o aumento da resiliência. Esta mudança surge do reconhecimento de que a proteção estrutural, embora podendo teoricamente ser alcançada, implicaria custos financeiros de tal modo elevados que a tornam incomportável e indesejável. Com efeito, os modelos atuais de governação do risco de inundações enveredam por abordagens que (i) consideram o papel das comunidades e dos indivíduos, (ii) incorporam formas de convivência com as cheias ("living with floods") (iii) e dão relevo à construção da resiliência entre as partes envolvidas como parte de uma estratégia de cooperação ("coping strategies") dentro das estratégias de gestão do risco (Dieperink *et al.*, 2013).

De seguida apresentam-se alguns estudos de caso que exemplificam modelos atuais e futuros de mitigação do risco de cheias e inundações.

As questões relacionadas com a sustentabilidade financeira das medidas estão bem presentes na análise que tem sido feita aos PAPI (*Programmes d'Action pour la Prévention des Inondations*) anteriormente referidos, em França (Erdlenbruch *et al.*, 2009). Estes planos traduzem uma política de redistribuição do risco ("risk-sharing policies") amplamente assente no redireccionamento da inundação ("overflooding") das áreas mais vulneráveis para as áreas menos vulneráveis, o que expõe os agricultores a maior risco. Esta prática levou as entidades locais de gestão do risco de inundação a introduzir medidas financeiras compensatórias entre umas e outras áreas, financiadas sobretudo pelos municípios (Figura 12). O estudo sublinha os resultados de um inquérito exaustivo aplicado à totalidade das 48 bacias com PAPI em vigor bem como aos diversos atores locais em quatro daquelas bacias.

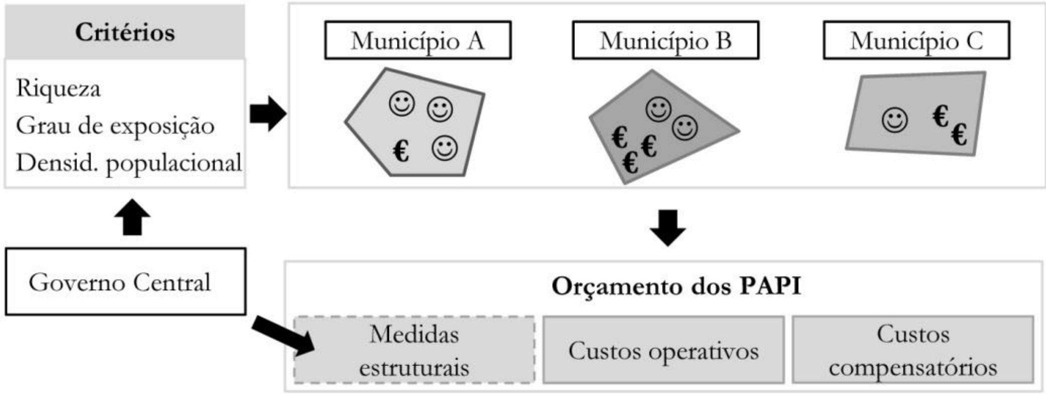

Figura 12. Mecanismos de financiamento dos PAPI (a partir de Erdlenbruch *et al.,* 2009)

Os resultados revelam que os mecanismos compensatórios correm o risco de não ser financeiramente viáveis, principalmente devido ao facto de limitarem a gestão do fundo compensatório a pequenas e isoladas unidades de gestão. Outra ameaça advém do elevado risco de compensação excessiva, por a avaliação da situação de "overflooding" face à situação de cheia e inundação normais não ser de fácil concretização. Como alternativa, são propostas algumas soluções de partilha do risco assentes na premissa de que em certas situações é mais barato compensar que prevenir – a prevenção é geralmente pensada a nível coletivo e a compensação é praticada num plano individual. Por exemplo, é proposta uma maior articulação entre as companhias seguradoras e as entidades gestoras dos PAPI:

- através de mecanismos de seguros privados para os agricultores, mas em parte subsidiados pelas entidades gestoras dos PAPI. As entidades gestoras dos PAPI cedem informação sobre o risco às seguradoras e estas aceitam cobrir as áreas intencionalmente inundadas. Isto retira às entidades gestoras o peso e o risco de gerir fundos de compensação, algo para o qual não estão vocacionadas;
- através de um fundo de compensação à escala da bacia envolvendo a atividade resseguradora. O sistema de compensação é definido pelas entidades gestoras dos PAPI mas na ocorrência de perdas excecionais, estas

conseguiriam ressegurar o risco recorrendo a instituições financeiras ("risk hedging").

Tomando ainda como exemplo o estudo de caso citado em Inglaterra (Cashman, 2011), a consciencialização para a necessidade de mudar as estratégias de gestão do risco surgem na sequência de cheias ocorridas entre os anos de 2000 e 2004 que deram origem a forte pressão pública e política no sentido de se encontrarem formas mais proactivas de resposta e preparação face ao risco. Algumas das formas encontradas foram: (i) a criação de um conselho consultor denominado como "advisory groups" para as questões da gestão da água; (ii) a implementação de "flood local action plans" ao nível da comunidade, com o objetivo de partilha de experiências e preocupações e de estímulo e regulação do diálogo entre as comunidades e as autoridades; (iii) o aumento da colaboração com as instituições académicas. Passados alguns anos da implementação destas medidas, o autor expressa a evidência qualitativa, baseada em inquéritos, de que houve um aumento da resiliência, sem que o mesmo possa contudo ser quantificável.

Na Alemanha, na bacia do Rio Reno, a influência que um cenário de mudança climática terá no aumento da probabilidade de inundações ao longo do rio Reno – e como isso interferirá com as estratégias de gestão do risco de cheias e inundações a longo prazo – é objeto de estudo consolidado (Te Linde *et al.*, 2010). Os desafios para a gestão do risco nesta bacia advêm do facto de que, num cenário de mudança climática, se uma dada estrutura de proteção – por exemplo, um dique – está projetada atualmente para uma determinada probabilidade de ocorrência a que corresponde um determinado caudal de ponta de cheia, em 2050 esse caudal corresponderá a uma probabilidade de ocorrência mais curta ou, para o mesmo período de retorno, corresponderá a uma ocorrência mais severa. Realçam-se assim metodologias que avaliem a eficácia das medidas de gestão do risco de inundação, assumindo cenários de mudança climática. Esse exercício foi realizado na bacia do Rio Reno para o ano de 2050, tendo sido consideradas as medidas constantes no Plano de Ação para as Inundações do Reno (APF), tendo sido propostas outras medidas adicionais que incluem: a restauração de meandros abandonados; a construção de um *bypass* hidráulico ao redor da cidade de Colónia; a implementação de mais bacias de retenção ("retention polders") para além das existentes; modificações ao uso do solo aumentando as áreas florestais; reflorestação do leito dos rios nas áreas a montante, como forma de reduzir a velocidade e beneficiar as áreas a jusante. O estudo incluiu uma reamostragem de dados meteorológicos e a aplicação de um modelo hidrológico, recorrendo ao programa SOBEK, que simule séries de caudal longas. Não obstante todas a medidas de mitigação aplicadas no âmbito do APF e as medidas adicionais não vigentes mas simuladas, o estudo conclui que as mesmas não serão suficientes para minimizar o impacto do aumento da probabilidade de inundação que se espera no futuro num quadro de mudança climática. Poder-se-á interpretar que a gestão do risco naquela bacia necessitará de outro tipo de respostas, porventura mais direcionadas para medidas não-estruturais, do prisma societal, que preparem para a convivência com o risco.

As estratégias de mitigação do risco de inundação na China demonstram igualmente a dinâmica e a versatilidade das soluções disponíveis. Num primeiro estudo de caso, descrito em Ge *et al.* (2011), aborda-se a problemática do risco de cheias e inundações na região do delta do rio Yangtze, uma área extremamente vulnerável a inundações (Chen *et al.*, 2013; Kobayashi e Porter, 2012), situação que se tem agravado recentemente devido ao aumento da densidade populacional e da atividade económica nas áreas expostas ao perigo. Os autores conduziram um inquérito com o intuito de compreender a perceção individual ao risco, tendo o mesmo sido aplicado às autoridades locais e à população em geral. Foram ainda realizadas entrevistas aos representantes das autoridades locais. Uma primeira análise aos resultados mostra que:

- os riscos percebidos pela população exposta (e o seu efeito multiplicador) revelam a presença do efeito de estigma na sequência do sismo de Sichuan;
- as respostas dos estudantes do nível intermédio ("college students") revelam que esse efeito de estigma está menos presente nos inquiridos com maior conhecimento sobre os perigos;

- verificam-se diferenças entre grupos sociais idênticos (ao nível da situação do agregado familiar, por exemplo) localizados na China e nos EUA, o que mostra que a cultura e a sociedade influenciam a perceção dos indivíduos ao risco;
- algumas atividades económicas estão a atuar como origem de constrangimentos à gestão do risco de inundação, sendo causa de subsidência do solo, escassez de áreas disponíveis para o escoamento e desvio da inundação para "diversion areas", isto é, áreas outrora não afetadas ou menos afetadas.

Perante estes resultados são sugeridas as seguintes estratégias: que o governo melhore a comunicação do risco e a educação para o risco das populações expostas; que o governo controle os usos do solo que se mostram obstáculo a uma melhor gestão do risco e que equilibre e concilie o desenvolvimento económico com a gestão do risco; que as áreas sobreinundadas, intencionalmente ou em virtude de ações realizadas noutros locais, sejam compensadas através de fundos especiais a serem coletados noutras cidades (ou seja, nos locais causadores da sobreinundação ou nos locais beneficiários da sobreinundação); que os governos locais providenciem maior apoio às medidas de mitigação do perigo.

Um fator comum que ressalta na maior parte das medidas sugeridas, é que estas se dirijam quase exclusivamente às entidades governativas, sendo atribuído pouco enfoque ao papel dado à participação pública e privada – ao contrário do que se sucede em relação ao estudo realizado em Bradford e em França, relativamente aos PAPI.

Em outro estudo de caso no contexto chinês é analisado o recurso a instrumentos financeiros como forma de mitigar o efeito das inundações (Chang, 2008), notando-se alguns aspetos similares com o estudo de Erdlenbruch *et al.* (2009), a propósito dos PAPI. No caso chinês, é proposta a criação de um sistema de permissões transacionáveis relativas à mitigação dos danos causados pelas cheias e inundações. Este instrumento económico visa encorajar a colaboração entre as zonas expostas ao risco a montante e a jusante, bem como entre os sectores público e privado envolvidos na gestão do risco de cheias e inundações. O sistema de permissões transacionáveis relativas à mitigação das inundações foi desenvolvido com base na investigação realizada e na experiência já vasta relativa à transação de permissões no âmbito de políticas internacionais de gestão ambiental. O sistema pode atuar também como um canal para partilha do risco envolvendo campos de atuação tais como a gestão das cheias, o planeamento do território e a conservação da natureza, através de uma abordagem financeira e estratégica do problema. Finalmente, o estudo conclui que o sucesso de medidas desta natureza depende fortemente da atitude dos decisores políticos em relação à descentralização da gestão do risco. Ao contrário do estudo de caso apresentado em Ge *et al.* (2011), no sistema de permissões proposto, o papel dos atores locais e privados é fundamental para a implementação desta medida de mitigação e de partilha do risco.

6.2 Envolvimento, comunicação e deliberação

No centro do esquema de governação apresentado na Figura 4 encontram-se o envolvimento, a comunicação e a deliberação. Com efeito, considerando que um dos objetivos principais de um processo de governação é o alcance de compromissos, ou seja, de níveis de aceitação dos resultados do processo de decisão que sejam toleravelmente satisfatórios face aos interesses defendidos pelos vários intervenientes (Aven e Renn, 2010), a participação dos mesmos não pode deixar de ser nuclear. Nos processos de governação do risco há inevitavelmente conflitos entre os intervenientes que produzem risco e aqueles que estão expostos a esses riscos (Figura 13). Por este motivo os processos de governação precisam encontrar metodologias que enquadrem os processos participativos de acordo com as características dos intervenientes.

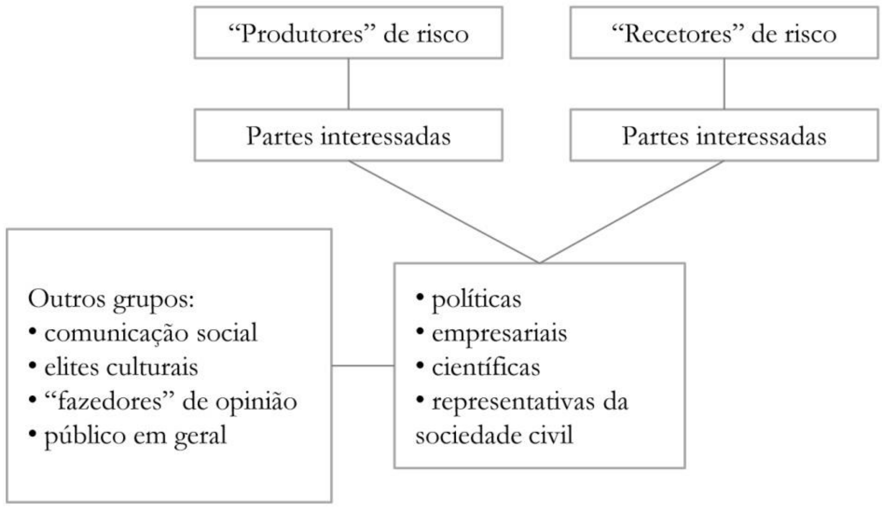

Figura 13. Posicionamento e tipologia de partes interessadas na gestão do risco (a partir de Aven e Renn, 2010)

O modelo "cooperative discourse" é uma ferramenta que procura incluir toda a pluralidade de conhecimentos e de valores em presença nos processos de envolvimento e participação pública (Aven e Renn, 2010). Os diferentes intervenientes iniciam-se no processo de governação com diferentes pré-condições quanto ao seu conhecimento das características do risco. Muitos deles não serão peritos em todos os domínios em causa – avaliação de perigosidade, vulnerabilidade, gestão do risco, etc. – e mesmo sendo perita num desses campos, existem diferenças de conceitos e de abordagem distintas entre as várias epistemologias. Perante isto, devem ser equacionados diferentes níveis e instrumentos de participação pública, de peritos e de partes interessadas de modo a garantir qualidade e eficiência do processo de participação. No modelo "cooperative discourse" defende-se que o discurso a adotar no processo de participação deve ser definido de acordo com a complexidade, ambiguidade e incerteza inerentes ao conhecimento do risco, não somente no seu processo físico mas também na forma como é percecionado (Aven e Renn, 2010). A aplicação dos instrumentos técnicos que organizam e concretizam a participação das partes interessadas, e que é parte integrante do processo decisório da própria governação, deve então basear-se nas características do risco – sua ambiguidade, incerteza e complexidade (Tabela IV).

Cada interveniente no processo de governação é caracterizado por um tipo específico de discurso, para o qual a participação deve adotar os instrumentos técnicos mais adequados. Por exemplo, os instrumentos usados na presença de um discurso epistemológico procuram produzir a mais adequada descrição ou explicação de um dado fenómeno. Os instrumentos usados neste tipo de discurso são as audições de peritos, os *workshops* científicos temáticos, as comissões de consultoria e as dinâmicas *Delphi* e *Group Delphi*.

Tabela IV. Definição do processo decisório com base na ambiguidade, incerteza e complexidade do risco.

Ambiguidade			Elevada
Incerteza		Elevada	
Complexidade	Elevada		
Processo decisório	Baseado em "knowledge and expertise"	Baseado na reflexão sobre a equidade e a partilha de benefícios e de custos	Baseado na definição de uma visão para o futuro, e em valores e aspirações essenciais
Discurso	Epistemológico	Refletivo	Participativo

Baseado em Aven e Renn (2010)

Em sentido restrito, o envolvimento pode passar unicamente pela comunicação do risco. Os benefícios da comunicação eficaz dos riscos de inundações para a população incluem: o aumento da confiança de quem recebe a informação face a quem a comunica; o aumento da preparação e conhecimento face ao risco (qual a sua probabilidade e quais as perdas esperadas); a educação para uma cultura do risco; a maior facilidade em alcançar acordos sobre as estratégias de gestão, como por exemplo, a aceitação da não implementação de medidas a montante que aumentem o risco a jusante; a maior recetividade para aceitar riscos num dado local em benefício de outros, se isso for devidamente compensado; o aumento da motivação para a ação em medidas preventivas e de reforço da resiliência (Kellens *et al.*, 2009; Kellens *et al.*, 2011; Rowan, 1991).

A comunicação do risco deve ser ajustada às necessidades específicas da população, dando a cada indivíduo a possibilidade de julgar por si o grau de risco em que se encontra e a tomar as suas decisões quanto às medidas de proteção e preparação (Kellens *et al.*, 2009). Algumas destas decisões podem ser exclusivamente individuais, ou podem exigir compromissos coletivos, podendo neste caso ser realizadas em conjunto com as autoridades políticas e com os agentes de proteção civil (Figura 14), no âmbito dos PGRI.

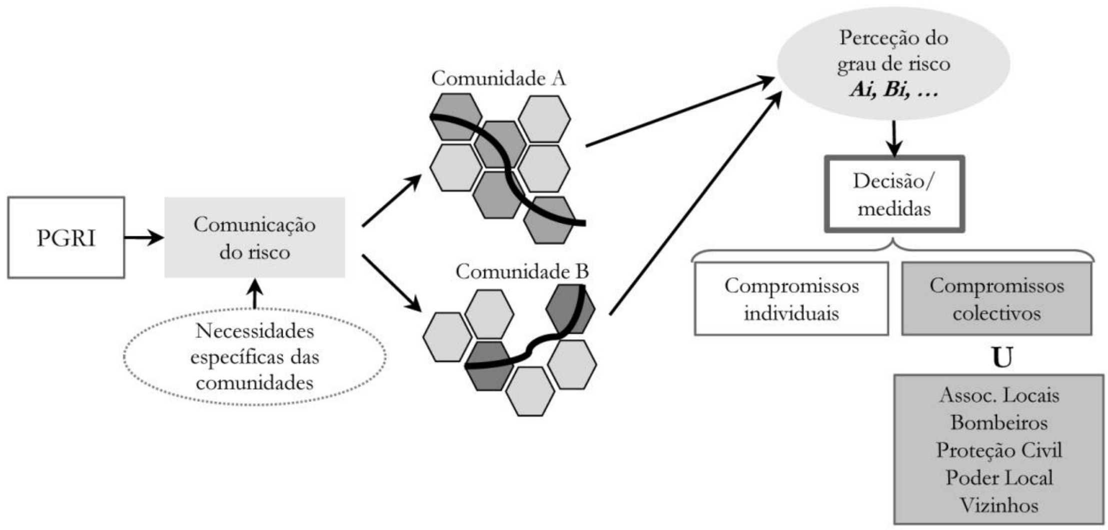

Figura 14. Alcance potencial da comunicação do risco às comunidades abrangidas pelos planos de gestão dos riscos de inundações (a partir de Kellens *et al.*, 2009)

A cartografia de risco tem um papel importante a desempenhar na comunicação do risco de cheias e inundações. Um dos aspetos menos compreendidos pela população relativamente ao risco – e que exige maior atenção na estratégia de comunicação – é a dificuldade em conceptualizar as ocorrências de baixa probabilidade mas elevado grau de perdas e danos (Carmen *et al.*, 2006). Esta evidência, associada ao argumento de "direito a saber" e ao impacto de causar um nível de alarme desproporcionado, devem ser adequadamente compreendidos e equacionados pelas entidades responsáveis pela gestão dos riscos de inundações. Os cenários de risco representados na cartografia devem ser claramente explicados, tendo em conta os aspetos acima referidos.

Para além das cartas de zonas inundáveis para áreas de risco, o Decreto-Lei n.º 115/2010 prevê também a elaboração de cartas de risco, onde se identificam as consequências em termos de pessoas, bens e atividades. Também aqui se coloca a necessidade de comunicar o risco pela cartografia de um modo adequado e eficaz, para vários tipos de recetores. Uma questão inicial se coloca: quais os critérios para se classificar a adequação ou a eficácia de um mapa? Esta questão encontra algumas respostas no projeto europeu RISKCATCH (Spachinger *et al.*, 2008). Este projeto teve por objetivo encontrar formas de elaborar cartografia suficientemente adequada para a comunicação do risco de inundações. Usando 17 tipos de mapas de risco mostrados a públicos igualmente diversificados (peritos, decisores políticos e população em geral), propõem um modelo conceptual de mapa de risco (Figura 15) do qual ressalta a simbologia e a cor – especialmente o contraste entre a informação que está na legenda e a cartografia de base – como fatores determinantes para a qualidade da leitura do mapa.

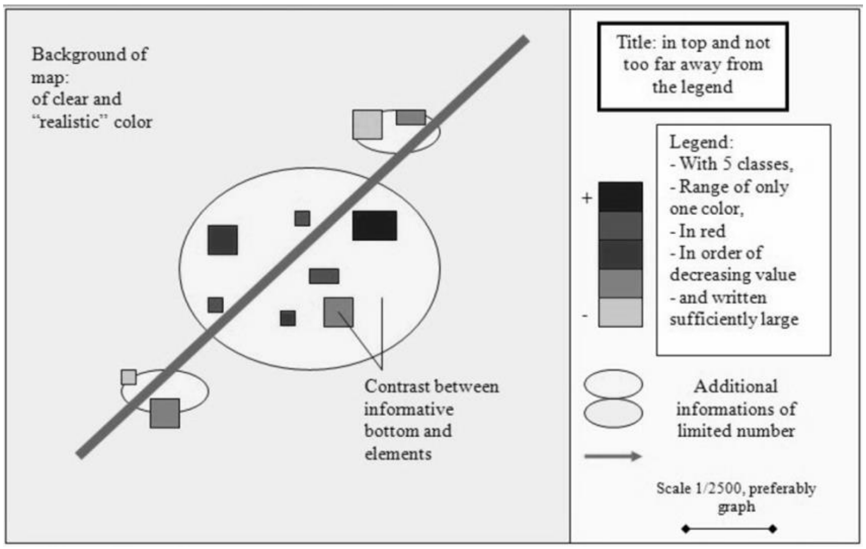

Figura 15. Modelo conceptual de mapa de risco proposto pelo projeto RISKCATCH (Spachinger *et al.*, 2008).

Outros fatores relevantes para a boa perceção do mapa são a presença de elementos textuais e a posição relativa dos diversos elementos. Fuchs *et al.* (2009) apresentam contributos para o mesmo objetivo e concluem sobre a necessidade de incorporar a perceção visual e cognitiva dos recetores na cartografia de risco de cheias e inundações produzida e sublinham que o desafio não reside unicamente em ser eficaz na transmissão da informação, mas em perceber se e como a informação comunicada é significativa quanto à criação de melhor consciencialização para o risco.

A estratégia de comunicação do risco pode equacionar a utilização de serviços WebSIG, com recurso a mapas do tipo estático ou dinâmico. Este recurso pode ser usado apenas para divulgação da cartografia de risco ou pode conter outro tipo de informação em tempo real sobre níveis pluviométricos e hidrométricos das estações, avisos e conselhos à população, recursos de socorro disponíveis, etc. A opção por divulgar ou não este tipo de dados deverá considerar o nível de preparação e de resiliência da população (fatores culturais e sociais). Os impactos de uma divulgação de conteúdos mal definida podem ser de sinal contrário ao pretendido, como sejam o pânico, o desejo de proteger bens e pessoas que se julga estar nas áreas afetadas e o *voyeurismo*, por exemplo.

Ao nível dos estudos de perceção do risco de inundações, Portugal dispõe já de alguma experiência – e.g. na bacia do rio Águeda (Coelho *et al.*, 2004) e em Setúbal (Correia *et al.*, 1994) – que constituem certamente uma base de suporte a processos participativos no âmbito da implementação da Diretiva 2007/60/CE.

6.3 Sistemas de aviso e alerta

Quando a incerteza relativa à perigosidade e à sua tradução em perdas é elevada ganham relevo as estratégias de gestão do risco de cheias e inundações que visam tornar tolerável a convivência com o processo de perigo, pelo aumento da resiliência das populações, agentes públicos e privados. Entre esse grupo de estratégias encontram-se os sistemas de aviso e alerta.

O novo quadro para a redução do risco de catástrofes (UNISDR, 2015b) identifica claramente num dos sete objetivos globais o "aumento substancial" da disponibilidade e acesso a sistemas de aviso e alerta. Com efeito, os sistemas de aviso e alerta vêm adquirindo um papel central nas estratégias de gestão do risco de cheia e inundações (Alfieri *et al.*, 2012; Priest *et al.*, 2011). A eficácia destes sistemas tem beneficiado largamente da melhoria da capacidade preditiva dos modelos numéricos hidrometeorológicos e da capacidade dos sistemas de informação em processar e difundir dados, por vezes, em tempo real. Simultaneamente, a opção por sistemas de aviso e alerta como uma das medidas não estruturais de gestão do risco resulta do entendimento de que as medidas estruturais apenas não garantem a redução do risco – podendo mesmo aumentá-lo (Kundzewicz *et al.*, 2010) – tendo como consequência que as comunidades precisam de encontrar melhores soluções de coexistir com a dinâmica fluvial (Priest *et al.*, 2011). Adicionalmente, estes sistemas são particularmente úteis na mitigação do risco nas situações em que o risco é suficientemente conhecido – quer a frequência da extensão da inundação e respetivas alturas, quer os elementos expostos em cada cenário e a respetiva vulnerabilidade – mas por vários motivos (técnicos, culturais, ambientais ou financeiros) não é possível atuar ao nível da sua redução (Samuels *et al.*, 2006).

Os sistemas de aviso e alerta são ferramentas fundamentais para a mitigação das perdas devidas a cheias e inundações. Frequentemente, os eventos ocorrem com uma elevada recorrência mas as respetivas perdas são reduzidas, aceites e previsíveis. Noutras situações, os eventos são extremos e de elevado potencial de perda, mas os decisores assumem a impossibilidade de os evitar. A aplicação de sistemas de aviso e alerta apresenta vantagens em ambos os cenários, permitindo minimizar os impactos humanos e materiais negativos (Alfieri *et al.*, 2011).

A título de estudo de caso, refere-se o exemplo da aplicação de tais sistemas na Austrália (Molinari e Handmer, 2011). A eficácia do sistema é medida através da quantificação de perdas evitadas. As ferramentas usualmente empregues para avaliar o impacto dos alertas na redução das perdas limitam-se à realização de análises pós-inundação ou a realização de estimativas da extensão de danos potenciais *versus* danos reais. Aqueles autores apresentam um método para a avaliação dos danos reais quando o alerta é ativado. A abordagem combina ciências sociais com abordagens de engenharia ao problema da eficiência dos sistemas de alerta a inundações. A partir de uma estimação dos danos potenciais feita através de curvas profundidade-perda ("depth-damage"), o método permite a identificação da redução do dano pela modelação de quantas pessoas responderam ao alerta. O modelo está conceptualizado na forma de árvore de eventos representando os passos do comportamento humano ao longo do processo de alerta à inundação. Dois estudos de caso australianos apresentados em Molinari e Handmer (2011) descrevem a aplicação desta metodologia. Os resultados destas aplicações no terreno demonstram a utilidade da análise em árvore de eventos, que também permitiu a identificação de fragilidades na cadeia de alerta, de que é exemplo o excessivo tempo de confirmação do alerta – antes do mesmo ser comunicado à população – tempo esse que pode ser crucial no caso de cheias rápidas. Recentemente, novos estudos têm sido conduzidos no sentido de avaliar a eficiência e a fiabilidade de sistemas de aviso e alerta a processos de perigo de natureza hidrogeomorfológica recorrendo, por exemplo, a análise de redes *bayesiana* (Sättele *et al.*, 2015).

A otimização de sistemas de aviso e alerta no sentido de prever e reduzir as perdas devidas a cheias e inundações em Portugal poderá beneficiar largamente da experiência de outros países europeus (Parker *et al.*, 2007; Priest *et al.*, 2011). Estes estudos revelam algumas limitações à eficácia destes sistemas na redução de perdas materiais ao nível da habitação, bem como de efeitos na saúde e na própria mortalidade, sendo a maior limitação o reduzido número de pessoas que efetivamente recebem os avisos, e a falta de preparação para reagir ao aviso (Parker *et al.*, 2007).

Parte II - RESULTADOS

7 Avaliação da suscetibilidade e da perigosidade

A Tabela V lista os artigos científicos que compõem os resultados relativos à avaliação da suscetibilidade e perigosidade a cheias e inundações.

Tabela V. Artigos científicos originais relativos à avaliação da suscetibilidade e perigosidade a cheias e inundações

Artigos basilares
Santos, Pedro Pinto dos; Reis, Eusébio (2015) Stream's flood susceptibility assessment: a cross-analysis between model results and flood losses. Submetido à revista Journal of Flood Risk Management.
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2011b) Comparing historical-hydrogeomorphological reconstitution and hydrological-hydraulic modelling in the definition of flood-prone areas - a case study in Central Portugal. Nat. Hazards Earth Syst. Sci., 11, 1669-1681.
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2012) Hydraulic modelling of the flood prone area in a basin with a historical report of urban inundation: the Arunca River case (Central Portugal). In Advances in Safety, Reliability and Risk Management. C. Bérenguer, A. Grall & C. Guedes Soares (eds) Taylor & Francis Group, London, 2936-2944. (ISBN 978-0-415-68379-1).
Artigos de suporte
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2011a) A bacia hidrográfica do rio Arunca. Factores condicionantes e cartografia dos processos de cheia/inundação In: Norberto Santos e Lúcio Cunha (Coord.) Trunfos de uma Geografia Activa. Imprensa da Universidade de Coimbra, ISBN: 978-989-26-0111-3, 879-887.
Cunha, Lúcio; Leal, Cátia; Tavares, Alexandre Oliveira; **Santos**, Pedro Pinto dos (2012) Risco de inundação no município de Torres Novas (Portugal). Revista GEONORTE, Edição Especial, Vol.01, 961-972.

7.1 Objetivos

O primeiro capítulo de apresentação de resultados trata o tema da avaliação da suscetibilidade e da perigosidade a cheias e inundações. Os artigos basilares apresentados descrevem a aplicação de metodologias muito distintas de obtenção de cartografia de suscetibilidade e perigosidade segundo as principais famílias de métodos de avaliação, concretamente, métodos geomorfológicos, históricos, hidrológicos e hidráulicos. Para além da análise da metodologia e resultados, é objetivo desta parte a demonstração das vantagens obtidas pela aplicação complementar dos conhecimentos característicos de cada método.

7.2 Desenvolvimento

Santos e Reis [s.d.] aplicam um método multicritério de classificação da suscetibilidade das linhas de água à inundação na bacia hidrográfica do rio Águeda. O método baseia-se em três tipos de informação: declive médio acumulado e escoamento acumulado, extraídos de modelos digitais de terreno hidrologicamente corrigidos, obtidos a partir da Carta Militar de Portugal Continental, na escala de 1:25.000, do Instituto Geográfico do Exército; e permeabilidade relativa acumulada extraída da informação litológica, afinada com a cartografia de ocupação do solo, de 2007, elaborada pelo extinto Instituto Geográfico Português, atual Direção-Geral do Território. A ponderação dos três fatores é validada através de bases de dados de perdas coligidas entre 1935 e 2010, que providenciam o conhecimento histórico dos registos de cheias e inundações associados a cada troço da rede hidrográfica.

Em Santos *et al.* (2011b) e Santos *et al.* (2012) são descritas, aplicadas e comparadas duas abordagens por vezes percebidas como opostas, na definição de áreas inundáveis na bacia hidrográfica do rio Arunca: (a) reconstituição histórica e hidrogeomorfológica, suportada por questionários à população, análise geomorfológica e deteção remota; (b) aplicação sequencial de métodos hidrológicos para a definição de dados de escoamento, utilizados posteriormente em dois contextos urbanos e dois contextos rurais, definidos pela geometria e condições de escoamento, segundo modelação hidráulica unidimensional. O mesmo princípio de atuação norteou a avaliação da perigosidade realizada no município de Torres Novas no âmbito de um trabalho aplicado coordenado pelo Prof. Doutor Lúcio Cunha (Cunha *et al.*, 2012).

7.3 Principais resultados

Em Santos e Reis [s.d.], a aplicação de um método multicritério de classificação da suscetibilidade para a inundação, baseado em Reis (2011), permitiu hierarquizar as linhas de água de acordo com a propensão para gerar cheias. O próprio método inclui a ponderação dos três fatores acima descritos, de acordo com o conhecimento histórico dos eventos de cheia ocorridos no passado na bacia do rio Águeda. Os resultados mostram que todas as combinações de fatores de ponderação testados apresentam coeficientes de correlação sensivelmente semelhantes, sendo que uma das combinações de ponderações – área acumulada com 85%, declive médio acumulado com 5% e permeabilidade relativa acumulada com 10% - abrange um maior número de ocorrências de perdas relativamente às outras combinações. A análise das ocorrências que ficam "de fora" do modelo é também em si um resultado interessante pois permite procurar outras causas, menos óbvias, para a ocorrência de perdas nesses locais. A metodologia proposta constitui uma forma de pré-avaliação das áreas mais propensas a inundação, podendo ser aplicada no contexto da avaliação preliminar do risco tal como preconizado na aplicação da Diretiva 2007/60/CE.

As mais-valias da aplicação complementar de diferentes métodos de avaliação da suscetibilidade e perigosidade a cheias e inundações são salientadas nos vários artigos, nomeadamente, pela aquisição de um maior conhecimento dos processos de perigo e, partindo dos princípios epistemológicos que estão na raiz de cada método, pela avaliação da sua adequabilidade para diferentes escalas temporais de planeamento. Essa adequabilidade parece ser condicionada pelo grau de intervenção humana sobre a planície aluvial, ao nível das modificações topográficas. Adicionalmente, foram realçadas as diferentes necessidades de cada método ao nível da exigência de dados de entrada e da complexidade tecnológica requerida por cada um. Verificou-se, por exemplo, que a aplicação do método de reconstituição histórica e hidrogeomorfológica pode complementar ou substituir a aplicação de modelação hidrológica e hidráulica nas áreas onde se verifique maior dificuldade na aquisição de dados hidrológicos e geométricos.

8 Análise do registo histórico de perdas por cheias e inundações

A Tabela VI lista os artigos científicos que compõem os resultados relativos à análise de bases de dados de perdas de cheias e inundações.

Tabela VI. Artigos científicos originais relativos à análise de bases de dados de perdas por cheias e inundações

Artigos basilares
Zêzere, José Luís; Pereira, Susana; Tavares, Alexandre Oliveira; Bateira, Carlos; Trigo, Ricardo; Quaresma, Ivânia; **Santos**, Pedro Pinto dos; Santos, Mónica; Verde, João (2014) DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal. Natural Hazards 72, 503-532.
Santos, Pedro Pinto dos; Tavares, Alexandre Oliveira; Zêzere, José Luís (2014) Risk analysis from hydro-geomorphologic disaster databases for local management. Environmental Science and Policy 40, 85-100
Artigos de suporte
Pereira, Susana; Zêzere, José Luís; Quaresma, Ivânia; **Santos**, Pedro Pinto dos; Santos, Mónica (2015) Mortality patterns of hydro-geomorphologic disasters. Risk Analysis [disponibilização eletrónica prévia à publicação]
Tavares, Alexandre Oliveira; Barros, José Leandro; **Santos**, Pedro Pinto dos; Zêzere, José Luís (2013) Desastres naturais de origem hidro-geomorfológica no Baixo Mondego no período 1961-2010. Territorium 20, 65-76.
Santos, Pedro Pinto dos; Tavares, Alexandre Oliveira; Zêzere, José Luís; Pereira, Susana (2013) Cheias e inundações na bacia do rio Lis: reconstituição histórica de desastres no período 1935-2010. Atas do IX Congresso da Geografia Portuguesa, Évora, 708-713.

8.1 Objetivos

A produção científica incluída neste capítulo tem dois objetivos principais: (1) demonstrar a estrutura e as características que compõem as bases de dados de perdas por cheias e inundações; (2) ilustrar a aplicação de métodos estatísticos de análise temporal e espacial que se podem experimentar a partir dos dados recolhidos, tendo em vista a produção de informação que ajude a compreender a relação entre o contexto territorial e o histórico de perdas.

8.2 Desenvolvimento

Os dois artigos que compõem o tronco principal deste capítulo (Santos *et al.*, 2014; Zêzere *et al.*, 2014) apresentam, descrevem e demonstram a utilidade prática de bases de dados de perdas associadas a riscos hidrogeomorfológicos, incluindo o risco de cheias e inundações. Estes dois artigos e os três artigos de suporte indicados sustentam a hipótese investigativa subjacente a esta parte: a tese de que as bases de dados de perdas são elementos fundamentais para a caracterização do risco, e que partindo dos seus dados se pode produzir informação que servirá de base à definição de estratégias e políticas de redução e mitigação do risco de cheias e inundações.

O estudo da mortalidade devida a desastres de natureza hidrogeomorfológica (Pereira *et al.*, 2015b) consiste num estudo pioneiro em Portugal, pela cobertura temporal e espacial que sustenta uma análise estatística aprofundada da distribuição, tendência, risco individual e societal das fatalidades devidas àqueles processos, bem como uma análise na perspetiva do género e dos contextos territoriais e locais em que ocorrem os desastres.

Os dois artigos de suporte referentes ao Baixo Mondego e à bacia do rio Lis exploram a maior escala e diversidade geográfica essa mesma hipótese. Em Tavares *et al.* (2013) é analisado o registo histórico de desastres de natureza hidrogeomorfológica no Baixo Mondego a partir da base de dados DISASTER (Zêzere *et al.*, 2014), salientando as diferenças entre o padrão de desastres que ocorrem no meio urbano e no meio rural, bem como a sua evolução temporal entre 1961 e 2010. No artigo referente ao rio Lis, salienta-se o distinto padrão geográfico entre as ocorrências de perdas com consequências humanas e aquelas em que se registram unicamente perdas materiais (Santos *et al.*, 2013).

8.3 Principais resultados

Em Zêzere *et al.* (2014) é apresentada a base de dados DISASTER e é desenvolvida uma análise estatística exaustiva aos principais campos descritivos das ocorrências de desastres de natureza hidrogeomorfológica – movimentos de vertente e cheias e inundações. Relativamente a estas últimas, que incluem 1622 ocorrências de desastres conclui-se que, embora as áreas mais afetadas apresentem uma predisposição natural para a ocorrência de cheias e inundações, a sua concentração pontual nas cidades e vilas localizadas ao longo dos vales do Douro, Tejo e Mondego demonstra a clara relação com a exposição da população.

Na região das Beiras, a análise da base de dados DISASTER e dos forçadores demográfico e urbanístico considerados, evidenciou a concentração de ocorrências com danos materiais nos concelhos onde se situam as principais áreas urbanas (Santos *et al.*, 2014). Contudo, ao considerar-se apenas as ocorrências com perdas pessoais (morte, desaparecimento, ferimento, evacuação e desalojamento) algumas áreas periféricas, menos densamente habitadas, registam ocorrências que igualam ou ultrapassam em gravidade aquelas verificadas nos concelhos com mais população. A análise apresentada culmina na definição de perfis de risco tendo como dados de entrada os resultados da análise *cluster* sobre os dados das perdas e danos e dos forçadores territoriais e os resultados das matrizes de risco.

9 Caminhos e desafios para a gestão do risco de cheias e inundações

A Tabela VII lista os artigos científicos que compõem os resultados relativos à reflexão sobre os caminhos e desafios que se colocam à gestão do risco de cheias e inundações.

Tabela VII. Artigos científicos originais relativos aos caminhos e desafios para a gestão do risco de cheias e inundações.

Artigos basilares
Santos, Pedro Pinto dos; Tavares, Alexandre Oliveira (2015) Basin flood risk management: a territorial data-driven approach to support decision making. Water 7, 480-502.
Santos, Pedro Pinto dos; Reis, Eusébio; Tavares, Alexandre Oliveira (2015) Flood risk governance towards resilient communities: opportunities within the implementation of the Floods Directive in Portugal. Atas da 2.ª Escola Doutoral da rede ANDROID em Resiliência aos Desastres 2014, 140-150.
Artigos de suporte
Tavares, Alexandre Oliveira; **Santos**, Pedro Pinto dos (2013) Re-scaling risk governance using local appraisal and community involvement. Journal of Risk Research 17(7), 923-949.
Santos, Pedro Pinto dos (2015) A gestão do risco de inundações em Portugal a partir da transposição da Diretiva Europeia 2007/60/CE. Reflexão para a sua aplicação mais ampla. Revista Electrónica de Investigação e Desenvolvimento 4, 1-12.

9.1 Objetivos

Nesta última parte são explorados caminhos de gestão do risco delineados a partir do conhecimento das perdas e dos contextos onde as mesmas ocorrem, bem como se apresenta uma leitura crítica da Diretiva Inundações, no seu papel de aumento da resiliência das comunidades ao risco de cheias e inundações.

Tendo como pano de fundo a Diretiva 2007/60/CE, os objetivos deste capítulo são: (i) demonstrar o contributo do conhecimento histórico das perdas e danos e do contexto territorial – físico, demográfico e socioeconómico – onde os mesmos ocorrem, à escala da bacia hidrográfica, nomeadamente em que medida as características das bacias moldam o registo histórico de perdas por inundação e como esse conhecimento pode resultar na produção de informação científica que contribua para uma melhor tomada de decisão na gestão dos riscos de inundações (Morss *et al.*, 2005); (ii) discutir o papel da legislação e instrumentos emanados da diretiva no contexto português, tendo presente o objetivo de longo prazo de construir comunidades mais resilientes aos processos de inundação e respetivos danos. Ao referir-se à diretiva, o contributo de um dos artigos focar-se-á em três esferas da governação do risco presentes naquele documento: a avaliação, a gestão e a participação pública e comunicação.

9.2 Desenvolvimento

Em Santos e Tavares (2015) é descrita uma investigação que surge na fronteira entre as fases de avaliação e de gestão do risco num processo de governação. Com efeito, aqui se aprofundam as ferramentas estatísticas que exploram o registo histórico de perdas por cheia e inundação e o contexto demográfico, socioeconómico e físico onde as mesmas ocorrem, culminando-se com o recurso a análise *fuzzy* para classificar e hierarquizar as estratégias de gestão do risco mais adequadas a cada bacia. As áreas de teste selecionadas são as bacias hidrográficas dos rios Vouga, Mondego e Lis, para as quais, para além dos registos contidos na base de dados DISASTER se dispunha de um registo bastante sólido de ocorrências com perdas unicamente materiais, extraídas dos jornais de âmbito regional consultados na região Centro. Este artigo assume assim três objetivos específicos sequenciais: (i) a análise e caracterização das perdas por cheias e inundações nas bacias hidrográficas selecionadas; (ii) a análise das relações entre esses padrões de perda e os contextos territoriais e (iii) a inferência de estratégias de gestão do risco de inundação através da aplicação de análise lógica *fuzzy*, como uma ferramenta de apoio à tomada de decisão.

Na tarefa de definir estratégias de gestão do risco de inundação que aumentem a resiliência aos desastres devidos a cheias e inundações, a Diretiva 2007/60/CE e a sua transposição para o contexto português surgem como instrumentos incontornáveis dada a abrangência por toda a União Europeia – todos os Estados-membros seguem o mesmo instrumento e caminho – e a obrigatoriedade legal para o curto prazo – os planos de gestão dos riscos de inundações devem estar concluídos até ao final de 2015. Em Santos *et al.* (2014) discute-se o contributo daquela diretiva europeia para a construção da resiliência aos desastres devidos a cheias e inundações. Não só os aspetos focados na diretiva relativos à avaliação do risco merecem uma análise crítica, como surgem como campos quase inexplorados a criação de modelos de participação pública e de intervenientes durante todo o processo de governação do risco.

Em Tavares e Santos (2013) descreve-se um estudo de caso à escala municipal, onde é adotado um modelo de governação do risco (IRGC, 2005, 2008) com forte envolvimento de intervenientes locais logo na fase inicial do processo identificando os principais riscos, entre os quais, o de cheias e inundações, culminando na elaboração de instrumentos de planeamento de emergência e de comunicação do risco. O contributo deste estudo de caso à escala local para a presente dissertação é o de constituir uma experiência concreta do candidato na definição e implementação de um processo de governação do risco que, não obstante não ser específico para o risco de cheias e inundações, poder-lhe-á ser adaptado e reproduzido nas suas etapas e estratégias de abordagem.

9.3 Principais resultados

Neste capítulo final relativo aos resultados, os artigos apresentados testemunham a "ponte" que se pode e deve realizar entre os resultados obtidos nas partes anteriores – avaliação de suscetibilidade e de perigosidade e análise de bases de dados de perdas – e a definição e execução de estratégias de gestão do risco de cheias e inundações, salientando o papel que a Diretiva 2007/60/CE poderá ter no processo de governação do risco.

O estudo apresentado em Santos e Tavares (2015) resultou na diferenciação, à escala regional, das três bacias hidrográficas consideradas em termos de "paisagem" de perdas humanas e danos materiais, de elementos expostos e características físicas relevantes para o risco de cheias e inundações. Partindo desta diferenciação, a metodologia *fuzzy* aplicada aos critérios de suporte à tomada de decisão "tempo" e "recursos" conduziu à hierarquização, ou priorização, da adequação de quatro grupos de estratégias de gestão, classificadas em operacionais e estratégicas.

Em Santos *et al.* (2014) acentuou-se a relevância do conhecimento como um dos pilares da construção de comunidades resilientes. Este processo, que pode ser apelidado de autoconhecimento quanto ao risco de cheias e inundações, e tornado obrigatório pela Diretiva 2007/60/CE, constitui por si um enorme aspeto positivo daquele documento. Um processo que positivamente se estrutura, segundo as boas práticas de governação do risco, nas fases de avaliação e gestão, tendo a participação como componente transversal, garantindo deste modo uma resposta holística ao problema das cheias e inundações. Não obstante os aspetos positivos, alguns desafios surgem à sua aplicação mais ampla, sobretudo quanto aos modelos participativos a adotar nas fases de elaboração e implementação das medidas dos PGRI; aos mecanismos financeiros que suportarão os planos; à articulação com os demais instrumentos de planeamento setoriais; os objetivos e metodologias para a realização da análise custo-benefício; e à monitorização dos planos.

Em Tavares e Santos (2013) demonstrou-se a possibilidade de – dentro do quadro conceptual e legal em vigor em matéria de gestão do risco e da emergência – iniciar e desenvolver processos de governação adaptados ao contexto físico, social e institucional local. Este nível de adequação depende largamente da capacidade inicial de auscultação de agentes e organismos interessados a que Aven e Renn (2010) designam de "concerns assessment". Esta avaliação norteou a subsequente avaliação do risco e permitiu avançar para os instrumentos de gestão de uma forma adaptada e legitimada. Como resultado, será futuramente possível definir mais eficientemente as medidas de gestão ao nível, por exemplo, do planeamento urbano, do desenho de rodovias, das ações de sensibilização e de comunicação do risco.

Parte III - DISCUSSÃO

10 Da avaliação da suscetibilidade e da perigosidade

Os resultados referentes à avaliação da suscetibilidade e da perigosidade a cheias e inundações realçam as mais-valias do uso combinado ou complementar de diferentes métodos de avaliação. A necessidade de aplicação de várias abordagens como meio de obter resultados mais fiáveis é reconhecida por diversos autores, desde os anos 70 do século passado (Baker, 1975) até à atualidade (Ballais *et al.*, 2011; Díez Herrero *et al.*, 2008; Gonçalves *et al.*, 2015; Mathieu *et al.*, 2007; Schumann *et al.*, 2009). Benito e Hudson (2010) propõem uma abordagem metodológica integrada para a produção de mapas de perigosidade baseados em registos, hidrológicos, geomorfológicos, de *paleofloods* e históricos (Figura 16).

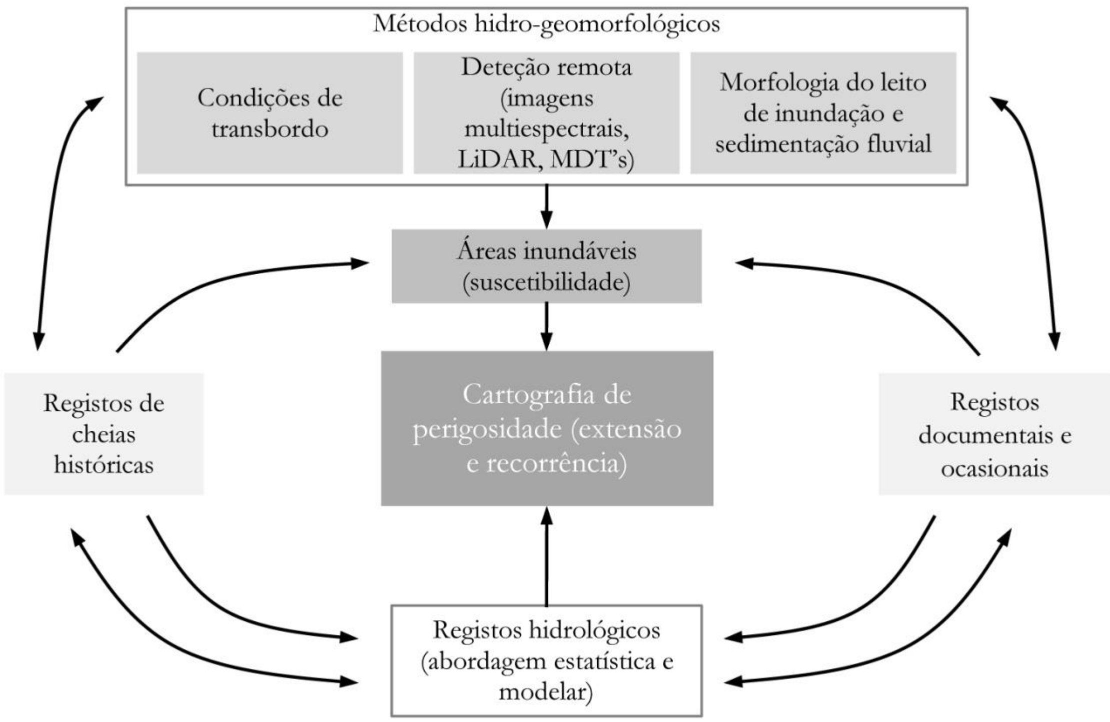

Figura 16. Aplicação de diferentes métodos e técnicas na avaliação da perigosidade de cheias e inundações (a partir de Benito e Hudson, 2010)

Pela Figura 16 se verifica que a aplicação de métodos hidrogeomorfológicos apoiada por registos de cheias históricas e registos documentais permitirá definir as áreas propensas a inundação, ou seja, a suscetibilidade. Apenas incorporando a dimensão temporal probabilística oriunda da análise hidrológica (por modelação ou análise estatística), se obtém a cartografia de perigosidade. Estudos recentes em Portugal baseiam-se na aplicação de métodos que combinam as tecnologias de informação geográfica com a abordagem geomorfológica e validação com registos históricos (Jacinto *et al.*, 2014; Reis, 2011), de onde resulta a hierarquização da suscetibilidade das linhas de água quanto à sua propensão para a inundação, e a definição das respetivas áreas inundáveis. Esta foi igualmente a abordagem metodológica seguida no estudo apresentado para a bacia hidrográfica do rio Águeda (Santos e Reis, [s.d.]).

Em Mathieu *et al.* (2007), o capítulo 4 – *Les études complémentaires de l'hydrogéomorphologie* – descreve as possibilidades de complementaridade entre os três métodos de avaliação da perigosidade, sintetizadas na Figura 17.

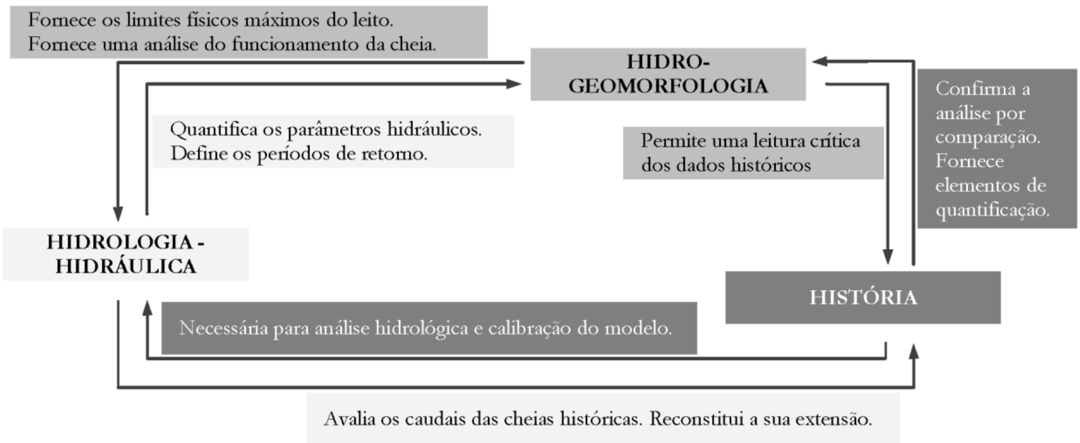

Figura 17. Complementaridade entre métodos de avaliação da perigosidade de cheias e inundações (Mathieu *et al.*, 2007)

Reconhecendo que os métodos são "mais complementares que contraditórios", os autores abordam a aplicação do estudo das cheias históricas e da modelação hidráulica como "estudos complementares" à abordagem geomorfológica, mantendo esta como basilar dos processos de avaliação.

A título de exemplo, entre os métodos hidrológicos e hidráulicos e os métodos hidrogeomorfológicos, refere-se a seguinte relação de complementaridade: os primeiros fornecem um valor de caudal de cheia – observado ou estimado – para uma dada secção de vazão para o qual se determinou um dado período de retorno. A partir desse valor de caudal, e por resolução da fórmula de Manning-Strickler, pode-se calcular a altura da cheia nessa secção, e comparar essa altura com a morfologia existente, associando assim um período de retorno a um dado terraço fluvial, patamar ou talude erosivo na planície aluvial.

No sentido inverso a existência de episódios de cheia, histórica e geomorfologicamente bem documentados, pode auxiliar na calibração de modelos hidrológicos e hidráulicos (Gonçalves *et al.*, 2015). Os modelos hidráulicos são por isso passíveis de validação através de levantamentos geomorfológicos e sedimentológicos (Baker, 1976; Lastra *et al.*, 2008).

No estudo realizado na bacia hidrográfica do rio Arunca (Santos *et al.*, 2011a; Santos *et al.*, 2011b) salientou-se a capacidade da intervenção humana para modificar a cartografia de áreas inundáveis ao nível da planície aluvial, sobretudo na cidade de Pombal, o que contribuiu para a identificação de alguns dos pontos fortes e fracos de cada metodologia constantes na Tabela VIII. Estudos recentes realizados na bacia do rio Arda (Arouca, Portugal) identificam e demonstram processos de alteração morfológica e das condições de escoamento como justificativos do aumento da exposição a cheias e inundações (Marafuz *et al.*, 2015).

Em suma, pode-se concluir que a complementaridade entre o método hidrológico e hidráulico e o método de reconstituição hidrogeomorfológica para definição de áreas inundáveis se revela sobretudo nos seguintes aspetos (Santos *et al.*, 2011b):

- melhor compreensão dos processos de inundação num contexto prévio e posterior a modificações morfológicas no leito de inundação;

- conhecimento das condições de inundação atuais (método hidrológico e hidráulico), com utilidade para opções fundamentadas de ordenamento do território, pelo menos durante o tempo em que as condições morfológicas e de escoamento permanecerem as atuais;
- conhecimento das condições de inundação a uma escala temporal mais ampla e menos sensível a alterações morfológicas recentes (método de reconstituição hidrogeomorfológica), e eventualmente não permanentes porque induzidas por ação humana;
- possibilidade de atribuição de um período de retorno aproximado à área inundável obtida por reconstituição hidrogeomorfológica nos troços onde a semelhança com a cheia centenária é elevada.

Tabela VIII. Principais pontos fortes e fracos de cada método aplicado na bacia do Rio Arunca.

Hidrológico e hidráulico	**Reconstituição hidrogeomorfológica**
Não interpreta a morfologia	Interpreta a morfologia
Com maior ou menor fiabilidade propõe probabilidades de ocorrência	Identifica sobretudo áreas de diferente suscetibilidade
Depende da existência de dados hidrometeorológicos	Pode recorrer, mas não depende, de dados hidrometeorológicos
Depende de dados altimétricos de elevada precisão (na Secção B, recorreu-se a dados na escala 1:2000).	Pode utilizar (mas não depende de) dados altimétricos de elevada precisão
Reage a modificações recentes na morfologia do leito	Reflete a situação de suscetibilidade para a inundação para uma escala temporal maior
Capacidade de realizar cenarização (eventos de cheia passados, desflorestação, alterações climáticas/ precipitações intensas)	Grande fiabilidade porque baseia a avaliação em processos fluviais já ocorridos e com reflexo na morfologia
Aplicação a grandes áreas difícil e cara (grande exigência em dados de entrada)	Relativamente mais barato e de mais fácil aplicação (pode ser aplicado com poucos dados de entrada)

Frequentemente, as fontes documentais suportam a aplicação de métodos hidrológicos e geomorfológicos na definição da perigosidade, isto é, definindo a extensão e a frequência da inundação (cf. Díez Herrero *et al.* (2008) e Figura 5). O objetivo com que no estudo realizado na bacia do rio Águeda (Santos e Reis, [s.d.]) se recorreu a fontes documentais hemerográficas é principalmente o de validar a classificação da suscetibilidade das linhas de água – e não a suscetibilidade de polígonos de inundação – através de registos históricos que comprovam a propensão das mesmas para a ocorrência de cheias. Naquele estudo se verificou que, quando as ocorrências registadas na imprensa não se enquadram no modelo, tal constatação abre caminho para a busca de outras causas para a ocorrência quer da cheia quer da perda, o que em si é igualmente uma vantagem do método aplicado.

Porventura a principal conclusão a extrair do capítulo referente à avaliação da suscetibilidade e da perigosidade a cheias e inundações é a de que cada método, isoladamente, não consegue abranger toda a complexidade dos processos de cheia e inundação, e consequentemente, a aplicação de um único método revela-se insuficiente para uma ótima avaliação da perigosidade. Esta conclusão é suportada pelos resultados que demostraram que a aplicação de diferentes métodos conduziu a uma melhor compreensão dos processos físicos na sua dimensão espacial e temporal, com vantagens óbvias para a prática do ordenamento do território e da gestão do risco de cheias e inundações.

A transposição da Diretiva 2007/60/CE para o direito interno através do Decreto-Lei n.º 115/2010, de 22 de Outubro, reconhece a dinâmica territorial e climática que condiciona as avaliações de perigosidade, elementos expostos e vulnerabilidade e, por inerência, de risco. O documento define portanto a obrigatoriedade de elaboração de cartografia de zonas inundáveis e de riscos de inundações para as áreas previamente identificadas e para diferentes cenários. Do lado da avaliação da perigosidade, saliente-se que o diploma interno que transpõe a diretiva não exclui nem privilegia qualquer método de definição de zonas inundáveis (cf. n.º 3 do artigo 7.º) pelo que importa aprofundar as relações de complementaridade entre eles. As vias para tal aprofundamento estão facilitadas em face dos desenvolvimentos recentes ao nível das tecnologias de informação geográfica, da deteção remota (AEA, 2010; AEE, 2015), da cartografia em tempo real, dos novos métodos de datação e da crescente disponibilização de registos históricos.

Qualquer que seja a abordagem, o ponto de partida de qualquer estudo sobre a suscetibilidade e a perigosidade será sempre a leitura geográfica do território nas suas componentes hidrológica e geofísica (e.g. Leal, 2013) buscando a sua aplicabilidade a problemas concretos da sociedade (e.g. Ramos *et al.*, 2010).

A execução de estudos comparativos com aplicação de cada método isoladamente, em diferentes contextos geográficos – morfológicos, geológicos, climáticos e de ocupação do solo – conduziria a uma melhor compreensão das respostas de cada método em cada um dos contextos, permitindo antever o efeito das modificações físicas e humanas que podem ocorrer nas diferentes escalas temporais e espaciais de planeamento. Certo é que um melhor conhecimento da suscetibilidade e da perigosidade a cheias e inundações conduzirá necessariamente a uma maior precisão na identificação dos elementos expostos, e consequentemente da capacidade preventiva e mitigadora das perdas.

11 Da avaliação de perdas

Os resultados apresentados demonstram o contributo das bases de dados de perdas devidas a cheias e inundações na gestão do risco.

A base de dados DISASTER (Zêzere *et al.,* 2014) apresenta-se como uma base de dados consistente e robusta. Consistente nos seus critérios de inclusão de ocorrências e exaustiva no período temporal e cobertura geográfica que representa quando comparada com bases de dados globais como a EM-DAT que apenas inclui ocorrências em que se verifiquem uma ou mais das seguintes condições: 10 ou mais vítimas mortais, 100 ou mais pessoas afetadas, declaração do estado de emergência ou a existência de um pedido de ajuda internacional. Certamente que a natureza, escala e objetivos de ambas são diferentes, porém, essas diferenças refletem-se em totais muito díspares de perdas com consequências humanas, o que não deixa de ter que ser assinalado.

A par desta discrepância nos critérios de inclusão, em Santos *et al.* (2014) evidenciou-se igualmente a relevância de incluir na análise as perdas materiais como complemento das perdas pessoais. Verificou-se também que os jornais de âmbito regional permitem abranger registos históricos que não são reportados nos jornais de cobertura nacional, mesmo relativamente às ocorrências com perdas pessoais. Neste estudo na região das Beiras é relevante realçar que, ao contrário das perdas unicamente materiais, as perdas humanas mais graves – morte e desaparecimento – não se apresentam correlacionadas com os forçadores territoriais considerados. As conclusões extraídas no estudo realizado para a bacia do rio Lis seguem na generalidade no mesmo sentido (Santos *et al.*, 2013). A distribuição da mortalidade devida a cheias e inundações surge associada a cursos de água de menor hierarquia e fora da cidade de Leiria ou de outros aglomerados urbanos na bacia do rio Lis. Estes factos contribuem para a definição dos fatores que poderão explicar então o padrão de distribuição da mortalidade, questão analisada com maior profundidade no estudo de (Pereira *et al.*, 2015b) para Portugal Continental. Aqui se concluiu que outros fatores que não os climáticos são responsáveis por uma desigual distribuição das condições de predisposição para o desastre, como sejam as alterações ao uso do solo e da exposição na envolvente às linhas de água, bem como modificações na vulnerabilidade social, com especial enfoque para as mudanças ocorridas no modo como ambos os géneros se relacionam ao nível da vida familiar e laboral, o que, em última análise, se reflete na vivência do território. Curioso ainda notar como a evolução do número de eventos e da respetiva mortalidade em Portugal apresenta forte semelhança com a tendência observada na Grécia, para um período de tempo relativamente semelhante também, ou seja, 1887-2010 (Karagiorgos *et al.*, 2013): aumento de registos de ocorrências de perdas, mas redução da mortalidade.

Paralelamente às bases de dados de perdas pessoais, a gestão do risco necessita de informação sobre as perdas materiais, considerando que a maior parte dos eventos de cheias e inundações se traduzem unicamente em perdas que afetam os bens, edifícios, equipamentos e infraestruturas (e.g. Tavares *et al.*, 2013), afetando assim o quotidiano desenrolar das atividades económicas públicas e privadas. A este nível, os vários trabalhos realizados evidenciam o meritório papel que a imprensa escrita tem na descrição deste tipo de perdas. Apesar de em número de ocorrências ser um tipo de ocorrência amplamente superior àquelas em que ocorreram perdas humanas, a descrição feita na imprensa escrita é contudo mais vaga, salientado casos pontuais de perdas em detrimento de uma análise mais global dos eventos, e com menos pormenores relativos à localização e ao tipo de perdas. Estes elementos são de um modo geral melhor caracterizados quando se trata de descrever as ocorrências com perdas humanas (morte, desaparecimento, ferimento, evacuação e desalojamento). Outros estudos internacionais realçam a relevância dos eventos com apenas perdas materiais, os designados “small disasters”, ao nível dos seus impactos no território e na socioeconomia (López-Peláez e Pigeon, 2011; Marulanda *et al.*, 2010; Voss e Wagner, 2010). Neste contexto, a informação disponível nas empresas seguradoras, assim como a sua experiência na aplicação de metodologias de avaliação do risco (e.g. ASP, 2014; Dias *et al.,* 2014) poderá efetivamente contribuir para melhorar o conhecimento sobre o potencial de perdas materiais devidas a cheias e inundações.

A avaliação de perdas e danos por processos naturais perigosos é uma fase fundamental nas estratégias de governação do risco. Ao mais alto nível da governação, o sucesso das estratégias é frequentemente monitorizado através de dados concretos de perdas expressas em vítimas mortais, feridos, deslocados e perdas económicas. É deste modo que começa por ser feito o balanço do período de 10 anos – 2005 a 2014 – em que vigorou o quadro de ação de Hyogo na declaração emanada da conferência de Sendai (UNISDR, 2015b). É igualmente usando indicadores de perdas – por exemplo, em valores médios de mortalidade e de pessoas afetadas num dado período ou em proporção do impacto económico no valor do produto interno bruto que se avaliam as tendências atuais. Com efeito, analisa-se frequentemente a probabilidade de ocorrência do perigo, por exemplo, de uma cheia centenária. O que será contudo mais relevante? Analisar a frequência do perigo ou a frequência das perdas que resultam da sua manifestação? Ambas as expressões estão fortemente associadas. A avaliação e monitorização da eficiência das estratégias de gestão do risco em vigor poderiam beneficiar com a análise cruzada daqueles resultados.

Tal como, a partir de bases de dados de precipitação, se definem limiares que desencadeiam a ocorrência de determinados processos de perigo, será exequível pensar que a partir de bases de dados de perdas e de bases de dados descritivas dos contextos geográficos se possam definir limiares de ocupação humana a partir dos quais se desencadeiam determinado tipo de desastres?

Como que em reflexo destas interrogações, as ações prioritárias emanadas de Sendai realçam a necessidade de registar e avaliar de um modo sistemático e mesurável as perdas por desastres (e.g. Yan-Jun *et al.*, 2015). Porém, o caminho indicado remete não só para as perdas diretas tangíveis e que são habitualmente coligidas pelas bases de dados, como também para a estimação dos impactos na saúde, educação, ambiente e património cultural (UNISDR, 2015b), bem como os impactos indiretos na atividade económica. A sua quantificação é reconhecidamente mais complexa mas útil, não obstante a incerteza associada (de Moel e Aerts, 2011; Thieken *et al.*, 2009; Zêzere *et al.*, 2008).

A este respeito, a Diretiva 2007/60/CE e a respetiva transposição através do Decreto-Lei n.º 115/2010, privilegia mais a identificação dos elementos expostos que a aprofundada caracterização das perdas e da vulnerabilidade. Existe contudo caminho para a proposta de metodologias assentes na exploração de bases de dados de desastres e em outras ferramentas de avaliação da vulnerabilidade.

A gestão do risco de cheias e inundações realiza-se sob a forma de uma miríade de políticas e ações, desde a redução do perigo, a redução da vulnerabilidade, a mitigação, a prevenção e a adaptação. Em suma, todas concorrem para o aumento da resiliência aos perigos, e em todas elas as bases de dados de perdas têm um contributo a prestar.

12 Da gestão do risco

Os estudos apresentados no âmbito deste grupo de resultados dedica-se à análise da complexidade, incerteza e ambiguidade que são características associadas à generalidade dos riscos naturais (Aven e Renn, 2010), e para as quais urge encontrar as ferramentas de apoio à decisão mais adequadas. Metodologias de análise *fuzzy*, como aquela que se exemplificou na aplicação às bacias dos rios Vouga, Mondego e Lis (Santos e Tavares, 2015), ao considerarem a incerteza através do conceito de "grau de pertença" traduzem-se numa forma de lidar com a incapacidade de alcançar soluções de gestão do risco para as quais se disponha de total certeza. No estudo apresentado para as três bacias hidrográficas da região Centro essa característica dos modelos *fuzzy* permitiu a proposta de estratégias de gestão – classificadas em operacionais e estratégicas, *"hard"* e *"soft"* – que possam ser equacionadas considerando os critérios tempo e recursos.

Dada a complexidade de processos causadores de inundação, de contextos distintos de vulnerabilidade e de elementos expostos, sensatamente, a Diretiva 2007/60/CE reconhece que "os objetivos da gestão dos riscos de inundações deverão ser fixados pelos próprios Estados-Membros e basear-se nas particularidades locais e regionais" (cf. n.º 10).

A gestão do risco envolve políticas e ações a diferentes níveis de decisão – nacional, regional e local – e apeladoras ao contributo de diferentes sectores de atividade e da administração pública, que devem considerar na sua génese as condicionantes físicas que moldam a paisagem do risco no planeamento territorial (Gomes e Chaminé, 2005; Tavares, 2000). Ainda assim, a imprevisibilidade dos eventos de menor probabilidade de ocorrência dificulta adicionalmente a definição das estratégias de gestão do risco. Por exemplo, o investimento em medidas de redução do risco que visem proteger os elementos expostos contra uma cheia com um período de retorno inferior a 20 anos, podem encorajar o desenvolvimento e a consolidação da presença humana atual, resultando num aumento do risco para uma cheia excecional – por exemplo, para uma cheia com uma periodicidade estimada de 200 anos (UNISDR, 2015a).

12.1 Complexidade, incerteza e ambiguidade

O risco de inundações é um risco marcado simultaneamente por elevada complexidade, incerteza e ambiguidade.

A elevada complexidade resulta de imediato da dificuldade em avaliar a perigosidade (Benito e Hudson, 2010; Díez Herrero *et al.*, 2008; Mathieu *et al.*, 2007), isto é, para além da definição da incidência espacial do perigo – ou seja, a suscetibilidade (Julião *et al.*, 2009) –, é muito difícil estimar a probabilidade de ocorrência, fundamental para a definição dos usos do solo em áreas de perigo. Na vertente da vulnerabilidade essa dificuldade está de igual modo presente (Few, 2003). As medidas adotadas no passado, em particular as de carácter estrutural, acentuam a complexidade de avaliação do risco, não obstante serem defendidas em determinados contextos (Jak e Kok, 2000). A existência de barragens e diques, por exemplo, introduz modificações na suscetibilidade à inundação, quer no espaço quer no tempo, com influência na configuração territorial dos elementos expostos no leito de inundação. Uma barragem pode, por exemplo, para um mesmo valor de caudal reduzir a suscetibilidade a jusante proporcionando uma maior ocupação do leito e, por consequência, um aumento dos elementos expostos face ao que seriam as prévias condições naturais de suscetibilidade. Estas estruturas de retenção estão, porém, sujeitas a falhas de funcionamento e ruturas cujas consequências ao nível dos caudais extremos debitados, podem eventualmente suplantar os níveis de cheia que seriam naturalmente expectáveis. Em face destas considerações é extremamente complexo proceder a uma avaliação dos benefícios e desvantagens de tais estruturas, em comparação com as situações prévias à sua existência (Kundzewicz *et al.*, 2010; Kundzewicz *et al.*, 1999). Num contexto de possível mudança climática, a avaliação da perigosidade e das perdas, em suma do risco, surge dificultada de um modo acrescido (Feyen *et al.*, 2011).

A elevada incerteza justifica-se pela diversidade de valores e interesses presentes: ao nível do leito de inundação, referindo-se às pessoas, bens e atividades que se desenrolam quotidianamente nas áreas de perigo (Gregory, 2005); ao nível da bacia hidrográfica, porque a gestão do risco também deve ser equacionada a este nível, afetando por isso também os interesses de quem usufrui dos recursos existentes ao longo de toda a bacia drenante.

A elevada ambiguidade deve-se, por um lado, à incerteza que o conhecimento científico atual acerca dos cenários de mudança climática provoca nas posições dos cidadãos e por inerência, na ação política (Few, 2003). Por outro lado, e em concreto com relação às cheias e inundações, a ambiguidade deve-se à diversidade de perceções/olhares dos cidadãos face ao risco (Affeltranger, 2001) expressas por: indiferença da parte de quem vive afastado das áreas de perigo e não aceita restrições ao seu usufruto do solo; leitura bifocal quanto aos efeitos das inundações fluviais (efeitos benéficos e prejudiciais das cheias); existência de experiências individuais e coletivas traumáticas, com capacidade para nortear a intervenção política.

Em conjunto, estas três características do risco de cheias e inundações são evidenciadas no atual quadro legal emanado da Diretiva 2007/60/CE.

12.2 Caminhos a explorar no âmbito da Diretiva 2007/60/CE

12.2.1 Conceitos utilizados

Um dos conceitos mais relevantes utilizados na diretiva é o de inundação. Recordando a definição expressa no n.º 1 do artigo 2.º da diretiva, e apresentada na Parte I, inundação é "a cobertura temporária por água de uma parcela do terreno fora do leito normal, resultante de cheias provocadas por fenómenos naturais como a precipitação, incrementando o caudal dos rios, torrentes de montanha e cursos de água efémeros correspondendo estas a cheias fluviais, ou de sobrelevação do nível das águas do mar nas zonas costeiras". O conceito adotado pode excluir alguns tipos de inundações urbanas, que por vezes não estão associadas a linhas de água, ou estando, não se lhes é possível determinar um "leito normal". Parecem ficar igualmente excluídas as inundações devidas a subida do nível freático. Certamente, o bom senso irá prevalecer não deixando que estas tipologias de inundação não sejam consideradas nas fases seguintes da implementação da Diretiva 2007/60/CE.

Outro conceito relevante é, por conseguinte, o de leito normal. Este é definido segundo um critério hidrológico – "a média dos caudais máximos instantâneos anuais" – frequentemente de difícil aplicação pela ausência de dados, e cujo significado depende do contexto geomorfológico. A opção poderia ser a definição do leito segundo critérios hidrogeomorfológicos.

Para finalizar, e para efeitos de compatibilização terminológica com outros documentos metodológicos de avaliação do risco, em concreto com o Guia Metodológico para a Produção de Cartografia Municipal de Risco e Para a Criação de SIG de Base Municipal (Julião *et al.*, 2009), o Decreto-Lei n.º 115/2010 poderia ter adotado os conceitos propostos naquele documento.

12.2.2 Avaliação do risco

O disposto no diploma quanto à fase de avaliação preliminar acentua sobretudo a necessidade de se proceder à recolha histórica e descrição dos eventos de inundações ocorridas, mais que a incidência espacial a grande escala e respetiva expressão cartográfica.

O diploma revela bom senso ao não requerer cartografia de perigosidade para diversos períodos de retorno (por exemplo 5, 10, 25, 50, 100, 500 anos), cuja validade e leitura seriam dificilmente compreensíveis por grande parte do público-alvo, quer decisores, quer população em geral. A definição das três classes de probabilidade nos cenários hidrológicos revela igualmente precaução ao se atribuir a classificação de "probabilidade média" aos processos com período de retorno de 100 anos (APA, 2014). As cartas de riscos de inundações (CRI) identificam para as zonas definidas na avaliação preliminar as potenciais consequências associadas à ocorrência das cheias. A elaboração das CRI implica uma avaliação prévia dos elementos expostos. O diploma circunscreve o modo como se deverá expressar a quantificação do risco: número de pessoas e atividades económicas afetadas, equipamentos e instalações que possam causar poluição ou acidentes industriais graves, infraestruturas críticas e património cultural nacional e mundial (para maior detalhe desta descrição ver o n.º 1 do artigo 8.º do Decreto-Lei n.º 115/2010). Porém, um maior enfoque na avaliação da vulnerabilidade das populações e elementos expostos providenciaria melhor informação de suporte à elaboração dos planos de gestão do risco.

Relativamente à avaliação da perigosidade, um aspeto merece ainda uma breve reflexão porque remete para as decisões a tomar ao nível dos instrumentos de gestão, e que se prende com o zonamento das áreas inundáveis. Frequentemente, expressa-se a perigosidade em termos da cheia centenária. É, porém, sensato reconhecer que nem toda a área incluída nesse polígono apresenta 1% de probabilidade de ser inundada porque – salvo nas situações de fundo de vale completamente plano, ou naquelas em que, por motivos diversos, o leito possa ter sido desviado ou regularizado – de um modo geral, as áreas mais próximas do curso de água apresentam uma probabilidade maior. Esta é uma fragilidade identificada em muitas abordagens tradicionais de avaliação do risco, levando por seu turno a tomada de decisões de gestão do risco igualmente inadequadas (Ahmad e Simonovic, 2011).

12.2.3 Gestão do risco

A Diretiva 2007/60/CE vem consolidar a adoção do critério hidrográfico como definidor das unidades de planeamento e gestão em matéria de temas relacionados com os recursos hídricos e, no caso concreto desta diretiva, com o risco de cheias e inundações. Como descrito ao longo da dissertação, muitos outros países assumem desde há longa data este critério. Os *Programmes d'Action pour la Prévention des Inondations* (PAPI) em França parecem assemelhar-se em vários aspetos aos PGRI previstos no Decreto-Lei n.º 115/2010, pelo que a sua formulação, conteúdo e modelos de atuação poderão constituir referências.

A escala de atuação dos PGRI é uma questão essencial para a sua eficiência. O diploma refere que se poderá elaborar um plano por região hidrográfica ou um conjunto de planos (n.º 8 do artigo 9.º). Esta questão não é negligenciável. Tavares e Mendes (2010) referem as vantagens de se focalizar a prevenção e gestão do risco ao nível local e municipal, de que são exemplos os planos municipais de emergência de proteção civil (PMEPC) e os planos municipais de defesa da floresta contra incêndios (PMDFCI). Porém, a par desta tendência de atuação, parece ocorrer um nível preocupante de incapacidade e/ou falta de sensibilização dos atores locais para a implementação de políticas de gestão do risco, que são definidas num plano nacional e regional, segundo lógicas *top-down* de atuação. Os mesmos autores dão como exemplos deste processo a avaliação do risco de cheias no concelho de Arganil, focalizada no curso de água principal, ignorando as cheias rápidas que ocorrem nas pequenas linhas de água e que causam maior grau de perda, tal como é referido pelos atores locais. De facto, os decisores locais debatem-se frequentemente com problemas como a falta de recursos financeiros disponíveis para as implementações requeridas ou a ausência de auscultação durante o processo de atribuição desses recursos.

O diploma possibilita que os PGRI prevejam a realização de inundações controladas – ver o n.º 6 do artigo 9.º, bem como Erdlenbruch *et al.* (2009) – algo que deverá merecer a devida consideração para aplicação nas áreas regularmente afetadas por este perigo, ou seja, as zonas de risco potencial significativo, na terminologia do Decreto-Lei n.º 115/2010). A prática de inundações controladas permite transferir o risco das áreas mais vulneráveis (normalmente as áreas urbanas) para as áreas menos vulneráveis (normalmente as áreas rurais), retardando e reduzindo o caudal de ponta de cheia nas áreas beneficiadas.

Para além desta possibilidade, de carácter inovador no contexto nacional, o mesmo n.º 6 contempla outras ações a desenvolver à escala da bacia hidrográfica, tais como, a promoção de práticas de utilização sustentável do solo, a melhoria da infiltração e da retenção da água, que revelam opções estratégicas a consertar com outros instrumentos de gestão territorial como sejam os planos de bacia hidrográfica, planos florestais, planos municipais e regionais de ordenamento do território, planos de defesa da floresta contra incêndios e planos de emergência de proteção civil.

O n.º 3 do artigo 9.º abre a possibilidade para a realização de uma análise custo-benefício (ACB) mas não é claro quanto ao objeto da análise. A questão tem bastante pertinência. Erdlenbruch *et al.* (2009) apontam relativamente aos PAPI os pontos fortes e fracos decorrentes da sua aplicação. Realçam a premissa da existência de solidariedade entre regiões como o motor dos programas e a insustentabilidade financeira devido ao custo excessivo das medidas compensatórias, como uma das principais ameaças à sua prossecução. Num cenário de opção por este tipo de ações, será necessário dispor de um conhecimento detalhado do grau de perdas, para uns, e de ganhos, para outros, o que requer que se proceda a uma avaliação rigorosa da vulnerabilidade e do valor dos elementos expostos em cada local.

Outros países – como por exemplo, o Canadá, no âmbito da avaliação dos custos e benefícios do *Flood Damage Reduction Program* (De Loë e Wojtanowski, 2001) – possuem vasta experiência na aplicação de metodologias de ACB a instrumentos de gestão do risco de cheias e inundações. Importa que aquela análise capte a totalidade de custos e benefícios, isto é, que seja inclusiva dos custos e benefícios que não se relacionam objetivamente com os PGRI. No citado exemplo canadiano, por exemplo, a metodologia aplicada identificou um conjunto amplo de custos e benefícios em áreas como a proteção ambiental e o ordenamento do território que não eram anteriormente considerados.

Quanto à articulação com os instrumentos de planeamento em vigor, nomeadamente em relação ao Decreto-Lei n.º 364/98, o texto de transposição da diretiva refere que "o presente decreto-lei não prejudica o disposto" nesse documento. Eventualmente, o Decreto-Lei n.º 115/2010 poderia ter concedido maior alcance a esta relação pelos seguintes motivos:

- as áreas inundáveis definidas ao abrigo do Decreto-Lei n.º 364/98, serão naturalmente identificadas também na fase de avaliação preliminar dos riscos de inundações, definida no Decreto-Lei n.º 115/2010, porque os critérios de decisão quanto a elaboração ou não de cartas de zonas inundáveis são igualmente abrangentes, sendo porventura ainda mais abrangentes neste último;
- subsistirá a eventualidade de duplicação ou contradição entre as restrições definidas ao abrigo do Decreto-Lei n.º 364/98 e aquelas provenientes dos PGRI a elaborar;
- a classificação da perigosidade e do risco definida nas CZI e CRI pode não concordar com a classificação apresentada nas cartas de zonas inundáveis elaboradas ao abrigo do Decreto-Lei n.º 364/98.

Por estes motivos sugere-se a consideração de um período transitório para transposição da cartografia e das restrições definidas ao abrigo do Decreto-Lei n.º 364/98 – e, segundo a lei, emanadas para os PMOT – para o conteúdo das CZI, CRI e dos PGRI, dado que as preocupações e orientações subjacentes a ambos os diplomas são convergentes. Após aprovação dos PGRI, poderia ser considerada a revogação do Decreto-Lei n.º 364/98 de modo a evitar possíveis incompatibilidades e sobreposições entre ambos (Santos, 2015).

No mesmo sentido, importa que sejam clarificados os âmbitos de ação dos PGRI e o respetivo sistema de financiamento, dado que a definição do objetivo principal – a redução das potenciais consequências – é demasiado vasta e pode implicar medidas de forte pendor financeiro. Em virtude do exposto, a ACB poderá ser realizada a medidas concretas a incluir nos planos, bem como aos próprios PGRI nos momentos de reavaliação cíclica.

Finalmente, e seguindo o espírito da Diretiva 2007/60/CE, o diploma estipula que deve ser dada preferência a medidas não estruturais de redução do risco. O Anexo a que se refere o n.º 2 do artigo 9.º e o n.º 3 do artigo 16.º explicitam claramente em relação aos PGRI que devem ser preferidas as "medidas não estruturais, ou seja, medidas que não impliquem a construção de diques ou outras obras de contenção que obrigam a custos de manutenção elevados" (n.º 5 da Parte A do referido Anexo).

12.2.4 Participação pública

Alguns estudos sobre perceção do risco de inundações mostram que frequentemente as comunidades não estão conscientes da situação de risco a que se expõem e desconhecem as atitudes a tomar antes, durante e pós a ocorrência (Pagneux *et al.*, 2011). Este facto reforça a convicção de que a participação pública e de partes interessadas é uma componente fundamental do processo de governação e gestão dos diversos riscos (Aven e Renn, 2010). Essa participação, no contexto dos PGRI, deve ir além da simples consulta pública ou da comunicação do risco através de mapas e sessões de sensibilização.

A transposição da Diretiva 2007/60/EC pelo Decreto-Lei n.º 115/2010 é muito clara quanto à promoção que deve existir da "participação ativa dos interessados na elaboração, reavaliação e atualização" dos PGRI (n.º 2 do artigo 14.º; ver também o artigo 10.º da Diretiva Inundações). Assumindo que todos os atores (decisores, comunidades, agentes de proteção civil, técnicos, etc.) são "interessados", importa perspetivar o modo como essa participação se pode concretizar em ações a incluir não apenas na fase de elaboração, como também nos próprios planos para nortear o seu funcionamento, posterior avaliação e atualização.

Ao acentuar as vertentes de prevenção, proteção e preparação e ao exigir que as autoridades competentes em matéria dos PGRI promovam a participação ativa dos interessados, a implementação da diretiva coloca o desafio do planeamento dessa participação e envolvimento.

O modelo "cooperative discourse" surge como um instrumento que permite a organização da participação ativa de todos os interessados. Pela sua metodologia, perspetivam-se as seguintes vantagens na sua aplicação, no âmbito dos PGRI, relativamente à:

1. Definição dos usos compatíveis e condições de ocupação do solo nas áreas de risco: atualmente, algumas experiências demonstram que é possível usufruir e habitar áreas com risco de inundações[5]. Um exercício do tipo de árvore de valores irá identificar os interesses em discussão (agrícolas, urbanísticos, ecológicos, culturais, etc.), sobre os quais a aplicação de instrumentos do discurso epistemológico irá resultar na apresentação das medidas (estruturais e, preferencialmente, não estruturais) que permitam a convivência e sustentabilidade (técnica, social, ecológica e financeira) dessas utilizações das áreas de risco. Finalmente, e segundo o modelo, a componente participativa que realça o saber e sentir da população, irá hierarquizar as opções surgidas e sugerir recomendações para a sua melhor aplicação.
2. Prática de sobreinundação – que consiste numa medida de natureza técnica que pode exigir alguma intervenção estrutural –, associada a mecanismos de compensação financeira, cuja natureza é não-estrutural, e na qual o modelo pode contribuir por meio de:
    - discurso refletivo instrumentalizado segundo a técnica de árvore de valores, respondendo à questão: a que é que os indivíduos e as partes interessadas dão valor? Dever-se-á proceder a hierarquização dos valores tangíveis e intangíveis a proteger e dos valores a sujeitar a sobreinundação periódica;
    - discurso epistemológico potenciado através de dinâmicas do tipo Delphi, contribuindo para o conhecimento das condições de inundação normais,

[5] Consultar a propósito os estudos feitos pelo Flood Resilience Group (http://www.floodresiliencegroup.org) e o exemplo de *Hafen City* em Hamburgo (http://www.hafencity.com).

isto é, prévias à aplicação de sobreinundação e cenarização das condições de sobreinundação; identificação das áreas a ser sobreinundadas; avaliação dos elementos expostos e da vulnerabilidade;

- discurso participativo, expresso através de painéis de cidadãos, numa atitude de escuta das comunidades acerca das soluções apresentadas e recolha das respetivas recomendações.

3. Definição das potenciais condicionantes ao uso do solo a definir ao nível da totalidade da bacia hidrográfica, por exemplo, restringindo alterações à ocupação do solo que signifiquem aumento da impermeabilização. Neste aspeto, o modelo irá lidar com um leque mais vasto de intervenientes, quer geográfica quer sectorialmente. Esta subida na escala poderá exigir variantes às dinâmicas e objetivos descritos quanto aos primeiros dois pontos.

A potencial aplicação de um modelo com as características do modelo "cooperative discourse" na governação do risco de inundações enfrenta alguns desafios. O primeiro relaciona-se com o facto de o modelo estar estruturado inicialmente numa lógica *top-down*, isto é, a iniciativa da implementação do processo de participação pública e de *stakeholders* pertence às entidades que gerem os riscos de inundações, porém a condução de todo o processo poderia ser mais alargada. Uma boa aplicação do modelo implicará a redução das "distâncias" entre as entidades competentes segundo a lei e as demais comunidades locais e partes interessadas. Caso contrário, e atendendo (i) à insuficiente maturidade da participação pública revelada nos processos de consulta pública (PDM, PBH, POOC, etc.), (ii) e à reduzida penetração na sociedade das organizações não-governamentais e associações de desenvolvimento locais, o modelo corre o risco de não atingir o desejável princípio de inclusão que deve nortear os processos de participação pública.

Finalmente, uma referência para o Sistema de Vigilância e Alerta de Recursos Hídricos, cuja criação está prevista no artigo 11.º e que pode constituir um instrumento de comunicação com a população e com os agentes de proteção civil, que deve ser potenciado e ambicioso nos seus objetivos.

Um aspeto relevante da participação pública nos processos de gestão do risco consiste na procura de equilíbrio entre uma visão essencialmente sociológica – não necessariamente dominante mas não negligenciável – que defende que o risco é primeiro que tudo uma construção social, mais que uma representação do perigo real, e uma visão focalizada nos processos físicos de perigo, que procura não sobrevalorizar essa perceção porque a mesma pode ser deformável pela ação dos meios de comunicação social ou por leituras intuitivas dos processos de perigo por parte da população. Esta dualidade é resumida por Klinke e Renn (2002) como realismo *versus* construtivismo. Estes autores propõem uma nova abordagem para a avaliação e gestão do risco em que contemplam a conjugação destes dois fatores prevalecentes nas equações de risco: perceção social e análise científica. É assumido que a natureza dual do risco exige uma estratégia igualmente dual da gestão do risco. Propõe-se nestas notas finais que a elaboração dos instrumentos de gestão do risco de cheias e inundações, os PGRI, incorpore este princípio, com enfoque nas especificidades biogeofísicas e socioculturais das diversas unidades de gestão. Neste processo poderão ser aplicadas técnicas de avaliação da tolerância ao risco e estratégias regulatórias como ALARA ("as low as reasonably achievable") ou BACT ("best available control technology"). Este tema representa porventura um dos maiores desafios à aplicação da Diretiva 2007/60/CE.

13 Notas finais

Após o trabalho realizado ao longo dos anos em que decorreu a primeira edição do programa doutoral em "Território, Risco e Políticas Públicas" espera-se, pelas metodologias aplicadas e pelos resultados alcançados, que se haja contribuído para o aumento do conhecimento científico relativo à problemática das cheias e inundações.

Ao contrário de outros riscos naturais caracterizados por uma incidência territorial de elevada ubiquidade (e.g. ondas de calor e sismos) o risco de inundação afeta faixas concretas de território, sendo contudo esta incidência o resultado do funcionamento de um sistema natural e societal mais amplo. As especificidades relativas à escala de atuação na avaliação e gestão do risco descritas por Tavares e Mendes (2010) assumem no risco de cheias e inundações elevada preponderância.

Tendo como pano de fundo os elementos que compõem os processos de governação do risco (Figura 18), os aspetos focados ao longo da presente tese procuram refletir sobre cada um desses elementos, experimentando as dificuldades inerentes e respondendo a alguns dos desafios que se colocam à governação do risco de cheias e inundações em particular. O mesmo quadro de governação apresenta paralelismos com as fases de implementação da Diretiva 2007/60/CE, transposto pelo Decreto-Lei n.º 115, de 22 de outubro.

Obviamente muitos dos elementos da governação não puderam ser considerados aprofundadamente neste trabalho dada a diversidade de dimensões presentes num processo de governação do risco. Entre eles, claramente se indicam as questões relacionadas com a análise – o termo *judgement* igualmente utilizado por alguns autores para descrever esta fase parece ser mais elucidativo –, a monitorização e controlo, e o envolvimento, deliberação e comunicação. Aven e Renn (2010) descrevem a fase de *judgement* como o momento em que, a partir do conhecimento gerado nas fases anteriores, se procede à avaliação da aceitação ou tolerância face ao risco. Assim, o *judgement* baseia-se sobretudo em dois tipos de informação – valores e evidências – sobre os quais se decidirá a relevância do problema e, consequentemente, o grau de empenhamento e de recursos necessários para o resolver na fase de gestão.

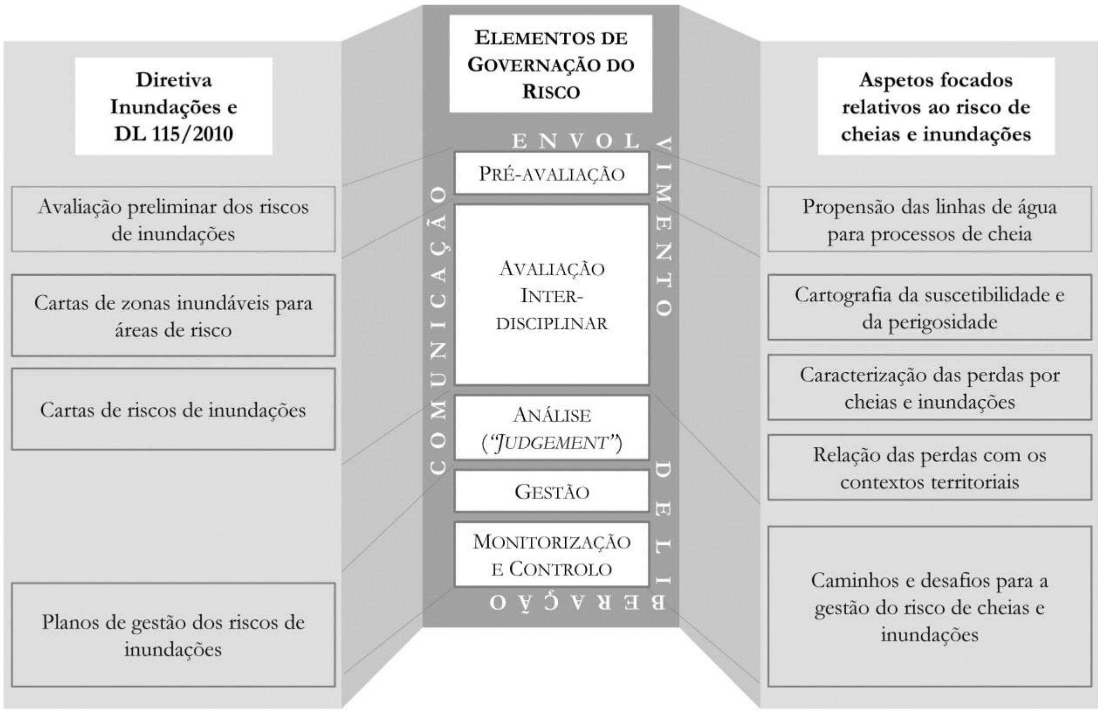

Figura 18. Paralelismo entre aspetos focados na tese, elementos de governação do risco e fases previstas na aplicação da Diretiva 2007/60/CE.

Os estudos apresentados demonstram a multidimensionalidade e diversidade que envolve cada cenário de risco de inundação ao nível da perigosidade natural e induzida pela ação humana, da vulnerabilidade e da tipologia de perdas. A complexidade dos sistemas naturais e societais que geram, e em que ocorrem, as perdas por cheias e inundações devem significar a conceção e aplicação das estratégias de governação do risco de acordo com cada contexto específico (Jha *et al.*, 2012; Yang *et al.*, 2013). Tais estratégias devem ser assumidamente integradoras de metodologias distintas, realçando as mais-valias de cada uma, e marcadas por uma abordagem multiescalar e multissectorial na gestão do risco.

O conhecimento é um dos pilares fundamentais de qualquer processo de governação do risco. No que concerne ao risco de cheias e inundações, estudos de base na área da hidrologia (Reis, 2006) definem metodologias replicáveis a outros contextos e apresentam resultados de elevado valor no suporte a estudos de suscetibilidade e perigosidade. No que respeita a estudos de vulnerabilidade, os decisores carecem porventura de conhecimento específico relativo à vulnerabilidade a cheias e inundações em Portugal. Em igual sentido, faltam estudos que quantifiquem as perdas materiais, diretas e indiretas, de uma forma tangível, objetivo para o qual o contributo do sector segurador poderia ser substancial. Esse interesse existe, como o demonstra o estudo apresentado em Jacinto *et al.* (2014).

Na gestão do risco de cheias e inundações, o conhecimento sobre o perigo, a exposição e a vulnerabilidade social são uma fonte de informação que permite definir as melhores estratégias para as situações específicas de cada combinação daqueles fatores (Koks *et al.*, 2014). Com efeito, sendo as comunidades tão heterogéneas, as medidas de gestão como sejam a mitigação individual, a evacuação e a cobertura por seguros não devem ser aplicadas homogeneamente a grandes áreas, mas adequadas às características socioeconómicas de cada família ou indivíduo (Koks *et al.*, 2014). Adicionalmente, a gestão do território – isoladamente ou perspetivada como medida de gestão do risco – beneficia amplamente da melhor compreensão da relação entre os processos físicos causadores de perigo, os contextos territoriais onde eles se manifestam e, finalmente, os impactos que resultam dessa intercessão. Em suma, a construção de comunidades mais resilientes aos processos de cheia e inundações tem por premissa a capacidade dos diversos intervenientes – onde se inclui obviamente a comunidade científica – em gerar e transferir conhecimento útil e aplicável nos processos de decisão e de gestão do risco.

A situação atual das cheias e inundações em Portugal é particularmente grave quando o aumento da exposição – e em matéria de gestão do território sabe-se como é complexo eliminar toda e qualquer forma de ocupação das áreas de perigosidade – não é acompanhado por uma redução da vulnerabilidade e aumento da resiliência. A Diretiva 2007/60/CE constitui então, para Portugal, uma oportunidade de aprofundamento das metodologias de gestão do risco de cheias e inundações a vários níveis. A obrigatoriedade cíclica de elaboração de cartas de zonas inundáveis e de risco proporciona uma oportunidade para desenvolver e consolidar a aplicação complementar de métodos de avaliação da perigosidade, sejam eles hidrogeomorfológicos, hidrológicos, hidráulicos, históricos, botânicos, etc. No campo da vulnerabilidade, o documento aprovado foi mais modesto, exigindo apenas a quantificação dos principais elementos expostos, deixando de fora uma análise mais aprofundada da vulnerabilidade na sua vertente sociológica. Contudo, que isso não signifique a menor aposta no desenvolvimento de metodologias de definição de indicadores de vulnerabilidade e da resiliência, e respetiva aplicação.

De resto, o estabelecimento deste quadro para a avaliação e gestão do risco de cheias e inundações, no qual o processo de perigo é assumido como natural e inevitável, constitui apenas por essa atitude de humildade e honestidade face à complexidade, incerteza e ambiguidade do sistema, um marco crucial para o alcance do objetivo de redução das perdas e danos causados pelas cheias e inundações em Portugal.

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ANEXOS

Anexo A - Participação Investigativa do Candidato

Tabela A1. Participação do candidato nos artigos basilares referentes à avaliação da suscetibilidade e da perigosidade

Artigos basilares
Santos, Pedro Pinto dos; Reis, Eusébio [s.d.] Stream's flood susceptibility assessment: a cross-analysis between model results and flood losses. Submetido à revista Journal of Flood Risk Management. Neste artigo, o candidato trabalhou de forma muito próxima com o coautor e orientador da presente tese para a correta aplicação da metodologia. Essa colaboração foi sobretudo relevante na discussão sobre a adequabilidade dos dados de entrada, sobre a classificação da permeabilidade relativa, na aferição dos fatores de ponderação e na interpretação de resultados.
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2011) Comparing historical-hydrogeomorphological reconstitution and hydrological-hydraulic modelling in the definition of flood-prone areas - a case study in Central Portugal. Nat. Hazards Earth Syst. Sci., 11, 1669-1681. Neste artigo, o candidato desenvolveu e aplicou os dois métodos descritos no artigo – método hidrológico e hidráulico e método de reconstituição histórica e hidrogeomorfológica – bem como procedeu à análise dos resultados obtidos e teceu as considerações sobre as características de aplicabilidade de cada método.
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2012) Hydraulic modelling of the flood prone area in a basin with a historical report of urban inundation: the Arunca River case (Central Portugal). In Advances in Safety, Reliability and Risk Management. C. Bérenguer, A. Grall & C. Guedes Soares (eds) Taylor & Francis Group, London, 2936-2944. (ISBN 978-0-415-68379-1). Neste artigo, o candidato desenvolveu e aplicou o método hidrológico e hidráulico para a definição das áreas inundáveis. Subsequentemente, a partir dos resultados obtidos, procedeu à identificação dos elementos expostos nas secções hidraulicamente modeladas e à comparação com a cartografia de áreas inundáveis em vigor, à altura.

Tabela A2. Participação do candidato nos artigos de suporte referentes à avaliação da suscetibilidade e da perigosidade

Artigos de suporte
Santos, Pedro Pinto dos; Andrade, Ana Isabel; Tavares, Alexandre Oliveira (2011) A bacia hidrográfica do rio Arunca. Factores condicionantes e cartografia dos processos de cheia/inundação In: Norberto Santos e Lúcio Cunha (Coord.) Trunfos de uma Geografia Activa. Imprensa da Universidade de Coimbra, ISBN: 978-989-26-0111-3, 879-887. Neste artigo, o candidato realizou a caracterização da bacia hidrográfica do rio Arunca, construiu modelos hidráulicos para quatro secções do rio Arunca e conduziu o trabalho de campo de reconstituição histórica e geomorfológica das áreas inundáveis, bem como a identificação dos pontos críticos de escoamento fluvial e urbano.
Cunha, Lúcio; Leal, Cátia; Tavares, Alexandre Oliveira; **Santos**, Pedro Pinto dos (2012) Risco de inundação no município de Torres Novas (Portugal). Revista GEONORTE, Edição Especial, Vol.01, 961-972. Neste artigo, o candidato construiu um modelo hidráulico de áreas inundáveis para um período de retorno de 100 anos, nos troços mais críticos do rio Almonda e da Ribeira do Alvorão à escala 1:10.000, e para as áreas urbanas que dispunham de cartografia a maior escala (1:2000), nomeadamente para Lapas e Torres Novas.

Tabela A3. Participação do candidato nos artigos basilares referentes à análise do registo histórico de perdas por cheias e inundações

Artigos basilares
Zêzere, José Luís; Pereira, Susana; Tavares, Alexandre Oliveira; Bateira, Carlos; Trigo, Ricardo; Quaresma, Ivânia; **Santos**, Pedro Pinto dos; Santos, Mónica; Verde, João (2014) DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal. Natural Hazards 72, 503-532. Neste artigo, a participação do candidato consistiu sobretudo na construção da base de dados DISASTER e na análise espacial e temporal da tipologia e distribuição das perdas pessoais.
Santos, Pedro Pinto; Tavares, Alexandre Oliveira; Zêzere, José Luís (2014) Risk analysis from hydro-geomorphologic disaster databases for local management. Environmental Science and Policy 40, 85-100. Neste artigo, o contributo do candidato regista-se fortemente em todo o artigo, desde a discussão introdutória, a definição e aplicação da metodologia de análise das perdas e do contexto geográfico onde as mesmas ocorrem, a análise propriamente dita e discussão de resultados.

Tabela A4. Participação do candidato nos artigos de suporte referentes à análise do registo histórico de perdas por cheias e inundações

Artigos de suporte
Pereira, Susana; Zêzere, José Luís; Quaresma, Ivânia; **Santos**, Pedro Pinto dos; Santos, Mónica (2015) Mortality patterns of hydro-geomorphologic disasters. Risk Analysis [disponibilização eletrónica prévia à publicação] Neste artigo, o contributo do candidato incidiu sobretudo na definição do quadro concetual do risco societal e sobre a análise dos resultados da distribuição da mortalidade segundo o género das vítimas e contexto territorial (urbano/rural).
Tavares, Alexandre Oliveira; Barros, José Leandro; **Santos**, Pedro Pinto dos; Zêzere, José Luís (2013) Desastres naturais de origem hidro-geomorfológica no Baixo Mondego no período 1961-2010. Territorium 20, 65-76. Neste artigo, o candidato colaborou na redação da introdução, na definição da metodologia e sua aplicação, na produção cartográfica, de gráficos e tabelas, na análise de resultados e na redação das considerações finais.
Santos, Pedro Pinto dos; Tavares, Alexandre Oliveira; Zêzere, José Luís; Pereira, Susana (2013) Cheias e inundações na bacia do rio Lis: reconstituição histórica de desastres no período 1935-2010. Atas do IX Congresso da Geografia Portuguesa, Évora, 708-713. Neste artigo, o candidato definiu os objetivos e a metodologia em conjunto com os coautores, sendo o restante trabalho de aplicação da mesma, redação do texto, produção cartográfica, de tabelas e de figuras, da sua autoria.

Tabela A5. Participação do candidato nos artigos basilares referentes aos caminhos e desafios para a gestão do risco de cheias e inundações

Artigos basilares
Santos, Pedro Pinto dos; Tavares, Alexandre Oliveira (2015) Basin flood risk management: a territorial data-driven approach to support decision making. Water 7, 480-502. Neste artigo, a estrutura e conceção da investigação, incluindo a abordagem metodológica, foram definidas pelos dois autores. Ambos participaram igualmente na redação da introdução, discussão e conclusões. A recolha de dados, sua análise estatística e elaboração de figuras e tabelas foram conduzidas pelo candidato.
Santos, Pedro Pinto dos; Reis, Eusébio; Tavares, Alexandre Oliveira (2015) Flood risk governance towards resilient communities: opportunities within the implementation of the Floods Directive in Portugal. Atas da 2.ª Escola Doutoral da rede ANDROID em Resiliência aos Desastres 2014, 140-150. Neste artigo a quase totalidade do texto é da responsabilidade do candidato, tendo o mesmo sido revisto posteriormente pelos orientadores da presente tese e por pares da rede ANDROID – Disaster Resilience Network (http://www.disaster-resilience.net/).

Tabela A6. Participação do candidato nos artigos de suporte referentes aos caminhos e desafios para a gestão do risco de cheias e inundações

Artigos de suporte
Tavares, Alexandre Oliveira; **Santos**, Pedro Pinto dos (2013) Re-scaling risk governance using local appraisal and community involvement. Journal of Risk Research 17(7), 923-949. Neste artigo, o candidato contribuiu maioritariamente na execução do "risk appraisal" e "risk characterization" – que inclui a auscultação de intervenientes locais, e a avaliação por diferentes metodologias da perigosidade, suscetibilidade, elementos expostos, localização do risco e vulnerabilidade social –, na elaboração e análise do plano municipal de emergência de proteção civil. Em resumo, o candidato contribuiu para a aplicação prática do modelo de governação do risco do IRGC.
Santos, Pedro Pinto dos (2015) A gestão do risco de inundações em Portugal a partir da transposição da Diretiva Europeia 2007/60/CE. Reflexão para a sua aplicação mais ampla. Revista Electrónica de Investigação e Desenvolvimento 4, 1-12. Este artigo foi escrito integralmente pelo candidato.

Anexo B1 – Trabalhos de Investigação Originais: Avaliação da suscetibilidade e da perigosidade

STREAMS' FLOOD SUSCEPTIBILITY ASSESSMENT: A CROSS-ANALYSIS BETWEEN MODEL RESULTS AND FLOOD LOSSES

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Abstract

This study describes a model which classifies the susceptibility of water streams to flooding. Three flood conditioning factors are considered: average slope, accumulated flow and average relative permeability. Multi-criteria analysis provided results for 11 combinations of weights. The results were then compared with the historical record of flood losses reported in newspapers between 1935 and 2010. Geology appears to function as a relevant factor in differentiating the major sub-basins. 86% of flood loss occurrences took place in streams identified by the model. The cross-analysis with flood loss data allows the identification of locations where disaster causes other than those explained by the conditioning factors should be searched.

The assessment of streams' flood susceptibility through this methodology is both useful in (i) data-rich contexts, where additional factors may be considered, and the availability of historical records helps validate the model and (ii) data-poor contexts where, data to run the model is easily found, although alternative validation data sources should be searched. By providing data on flood susceptibility, confronted and validated with the historical record of flood damages, this study provides a preliminary assessment of flood hazard with the ability of being performed previously to more thorough flood hazard mapping studies.

Keywords: stream, flood, susceptibility, historical, loss, data

1. Introduction

Floods are inevitable processes which account for 33% of the global average annual losses (AAL) caused by natural hazards, this is, 104 billion USD (UNISDR 2015a). In fact, disasters caused by floods affect more people worldwide than any other hazard (UNISDR 2015a). A disaster is always the outcome of the manifestation of a hazardous process, taking place in a given human system with its own social, economic, institutional and cultural properties (Brooks 2003). These figures highlight the need to improve our knowledge on the factors that trigger and condition a flood disaster event, which is one of the priorities of action exhaled from the Conference of Sendai (UNISDR 2015b).

Complexity, together with uncertainty and ambiguity, is a common characteristic in risk governance processes (Aven and Renn 2010). Dealing with complexity in flood risk governance is instantly expressed in the diverse application of methods that aim at assessing flood hazard – i.e., the spatial incidence and the probability of the flood (Benito and Hudson 2010; Díez Herrero et al. 2008; Mathieu et al. 2007). Flood hazard assessment technics and methodologies are frequently grouped in three major families: geologic and geomorphologic, hydrologic and hydraulic and historical (Mathieu et al. 2007; Díez Herrero et al. 2008). The application of such methodologies and the respective validity of results is even more complex to comprehend in contexts of climate change (Few 2003). The use of DEM-derived data to assess flood hazard combined with vulnerability indices is a useful approach in comprehending the relations between the physical processes and the contexts in which flood disasters take place (Dingguo et al. 2007).

Several factors influence the propensity to flooding – geology, land use, morphology, slope, flow accumulation, rainfall, etc. – the pertinence of their use being dependable on the distinct scales of analysis (Yahaya et al. 2010; Santangelo et al. 2011; Collier and Fox 2003; Kourgialas and Karatzas 2011). The established relations between factors are frequently defined by multi-criteria analysis (e.g. (Kourgialas and Karatzas 2011), although other statistical methods such as machine learning are also commonly used (Tehrany et al. 2014; Tehrany et al. 2015). In certain geographical contexts where resources are scarce – either the existence of input data to run hydrologic and hydraulic flood models, time to conduct field studies of fluvial geomorphology, or by other financial or technical constraints – the availability of tools that provide hazard assessments less depending on such requirements is a valuable asset (AOS 1991; Hagen et al. 2010; Nobre et al. 2011; Yan et al. 2014a; Yan et al. 2014b). The study presented in this article is in line with the purposes expressed in these examples, namely, by exploring the use of elevation models and data commonly available regarding permeability (e.g. land use and geology) to identify the areas more prone to flooding. Additionally to the consideration of such conditioning factors, the use of historical flood data is a useful resource in understanding the spatio-temporal patterns of natural disasters (Yi et al. 2012) and their application in the improvement and validation of flood hazard assessments is a common approach (de Moel et al. 2009; Barnolas and Llasat 2007; Prinos 2008). The use of historical data is also applied to calibrate parsimonious models for the assessment of flood hazard at the nationwide scale (Hagen et al. 2010). The use of this type of data is not always possible – particularly in data-poor contexts – but whenever existent, it provides a more accurate assessment of flood frequency and extent (Benito and Hudson 2010).

The methodology applied in this study was first described and applied in Portugal (Reis 2011) as a tool that provides a classification of water courses in regard to their susceptibility to flooding. The method also foresees the definition of flood prone areas although this part of the method is not applied in the current study. First applications of the described methodology aimed at supporting the definition of a Portuguese legal instrument, the National Ecological Reserve (REN), which regulates the compatibility of certain land uses and activities with a typology of areas, one of them being those threatened by flooding. The method has since been applied in several areas, in Portugal, Morocco and Cape Verde, in the context of MSc thesis (Ascenso 2011). Recently, an adaptation of the original methodology was presented (Jacinto et al. 2014) and applied to the entire area of Continental

Portugal and validated with the historical records of flood losses collected under the DISASTER project (Zêzere et al. 2014). In this nation wide application of the method, a better consideration of the different flood mechanisms (e.g. progressive and flash floods) at different spatial scales is attempted. The final result consists of a classification of flood susceptibility not only in water courses but to the entire territory, including slopes and hill tops.

2. Methodological approach

In this section, a general description of the streams' flood susceptibility (SFS) model is done (Figure 1), considering the research objective of mapping the propensity of streams to processes of fluvial flooding.

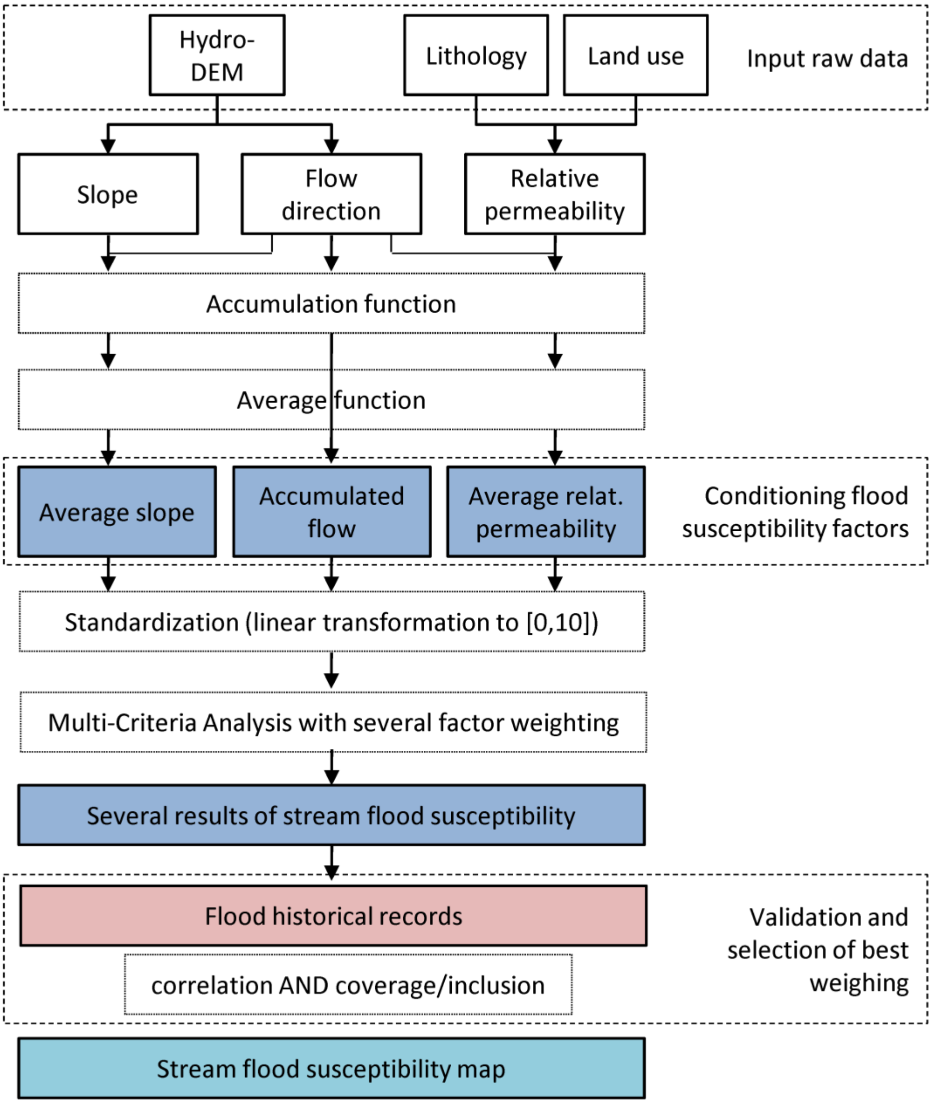

Figure 1. Methodological sequence of the stream flood susceptibility assessment (based in Reis, 2011).

Stream susceptibility to flooding is dependent of a diverse range of variables. It is assumed that those which condition quantity and velocity of superficial flowing waters are the most relevant to flooding. For this study, a hydrologically corrected Digital Elevation Model (DEM), geology and land use data constitute the initial input data from which three flood conditioning factors are derived: average slope, accumulated flow and average relative permeability. Slope, flow and permeability have distinct roles in a stream's propensity to flooding and, therefore, the best possible combination of these factors is assessed using flood historical records. All GIS procedures are done using ArcGIS®. The detailed methodological approach is further discussed in sections 3.2, 3.3 and 3.4, as the method is applied to a specific watershed identified in section 3.1.

3. Application

3.1 Study area

The Águeda river basin is located in the Central region of Portugal and is part of the Vouga river basin (Figure 2). Distinct morpho-structural units translate in distinct geologic features, which control morphology and slope. Slope is generally higher in the eastern sector of the Águeda river basin, in the older formations of the Hesperian Massif. Altitudes in the entire basin range from 1070 m in the eastern sector to 6.7 m in the baseline, at the confluence with the Vouga river.

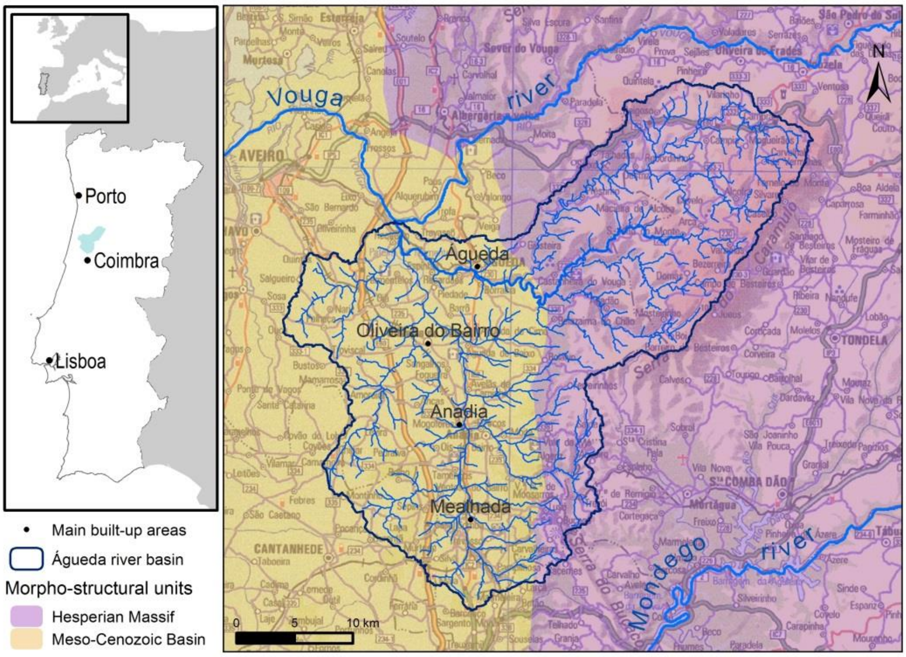

Figure 2. Geographical context of the Águeda river basin.

The drainage network is divided in two major sub-basins: the Águeda sub-basin and the Cértima sub-basin. Thus, the entire Águeda basin has two main water courses – the Águeda river which direction is W-E, and the Cértima river which direction is S-N. The lower reach of the Cértima river consists of a natural lagoon denominated “Pateira de Fermentelos”. Elevations in the margins of this lagoon reach 3 meters, which is lower than in the Vouga river floodplain where the confluence with the Águeda river occurs.

The city of Águeda is the main built-up area in the entire basin and is crossed by the Águeda river. The Cértima river also passes by important built-up areas – Mealhada and Anadia – and other smaller but continuous urban areas, disposed in a N-S axis, which developed particularly in the 20th century around the railway and the highway which connect the capital city, Lisbon, to Porto, the second major city. Forest land predominates in the Águeda basin, particularly in the mountainous area. In the western sector, in the low lying areas under 100 m, agriculture, residential and industrial uses predominate.

3.2 Factors of flood susceptibility

Accumulated flow (A_f)

Accumulated flow (A_f) in a given cell is a value that represents the number of upslope cells which flow into it. First step in the calculation of A_f is to obtain flow direction from a hydrologically corrected DEM. This DEM has a raster resolution of 10 meters and was obtained from contour lines 10 meters equidistant, from the Army Geographic Institute (IGeoE)[1] at scale 1:25 000. Flow direction – calculated with the hydrologic set of tools of ArcToolbox® from ArcGIS® - is then used to obtain A_f using the same set of GIS tools. A_f constitutes the first flood conditioning factor.

Average slope (A_s)

For the calculation of the second conditioning factor, average slope (A_s), slope in degrees is first calculated from the hydrologically corrected DEM. The next step is to perform flow accumulation in ArcToolbox® using the previously obtained flow direction and using slope in degrees as a weight factor, which results in accumulated slope (Acc_s). This attributes to each downstream cell the sum of slopes in the cell immediately upslope of it. Finally, A_s is obtained as the quotient between Acc_s and A_f (Eq. 1).

$$A_s = \frac{Acc_s}{A_f} \qquad \text{(Eq. 1)}$$

Each cell value of A_s represents the average slope of all the cells that drain into it.

Average relative permeability (A_{rp})

Relative permeability is evaluated from geologic and land use data. The geologic information is obtained from official cartography produced by the Portuguese Energy and Geology Laboratory (LNEG)[2] at scale 1:500 000. Land use is obtained from the official Land Use Chart of 2007[3], which has a minimum unit of representation of 1 hectare. Geologic formations are ranked in the interval

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[1] IGeoE (several dates). Portugal’s Military Chart, 1:25 000. Lisbon, Army Geographic Institute.
[2] LNEG (1992) Portugal’s Geologic Chart, 1:500 000. 5th Edition. Lisbon, Energy and Geology Laboratory.
[3] IGP (2007) Portugal’s Land Use Chart – 2007. Lisbon, Portuguese Geographical Institute.

between 0 and 10, according to their relative permeability (Table 1). For example, minimum relative permeability (score 2) is found in the Triassic-Jurassic formations composed of red sandstone, and in the Ordovician quartzite and schist. Maximum relative permeability (score 10) is found in the Quaternary fluvial terraces, sands and gravels, located in the western sector of the study area. Land use classes are ranked with zero to impermeable surfaces, 0.5 to public gardens, outdoor sport and leisure areas, and 1 to natural, forest and agricultural areas.

Table 1 – Relative permeability of geologic formations.

Lithology	Relative permeability
Ordovician vulcanite and undifferentiated carbonate rocks	2
Ordovician quartzite and schist	2
Triassic-Jurassic red sandstone	2
Proterozoic schist, greywacke and acid vulcanite	3
Cambrian turbidites and conglomerate	3
Ordovician schist, siltstone and sandstone	3
Cambrian granite	4
Carboniferous pelite, sandstone and conglomerate	4
Jurassic dolomite	5
Tertiary sandstone and conglomerate	5
Cretaceous sandstone	6
Upstream alluvium	6
Cretaceous limestone	7
Jurassic limestone and dolomite	8
Pliocenic sands and sandstone	8
Downstream alluvium	8
Quaternary fluvial terraces, sands and gravels	10

The two layers of information are then multiplied using GIS tools, resulting in relative permeability (R_p). R_p values are inverted so that low scores of R_p are associated with high capacity to generate superficial runoff. Similarly to the procedure regarding the slope, performing flow accumulation with ArcToolbox® using R_p as weight factor and the initially obtained flow direction, results in accumulated relative permeability (Acc_{rp}). As done for slope, Acc_{rp} is divided by A_f, from which the third conditioning factor, average relative permeability (A_{rp}), is obtained (Eq. 2). A value in this factor represents the average relative permeability of all the cells that drain into it.

$$A_{rp} = \frac{Acc_{rp}}{A_f} \qquad \text{(Eq. 2)}$$

Linear transformation and classification

The three calculated conditioning factors are linearly transformed to values in the interval [0, 10]. A_{rp} is already in such interval thus no transformation is needed.

Initial values of A_f varies between 1 and 9689420 and the transformation is done by applying the equation $y=1.032^{-6}x$. Initial values of A_s varies between 0 and 41.85 and the transformation is done by applying the equation $y=0.239x$.

Cartographic expression of flood susceptibility conditioning factors

Applying the above described methodology, the accumulated flow, average slope and average relative permeability result as mapped in Figure 3. Slope and relative permeability show notorious differences between the old and more consolidated formations of the Hesperian Massif and the Triassic and post-Triassic formations of the eastern sector of the basin.

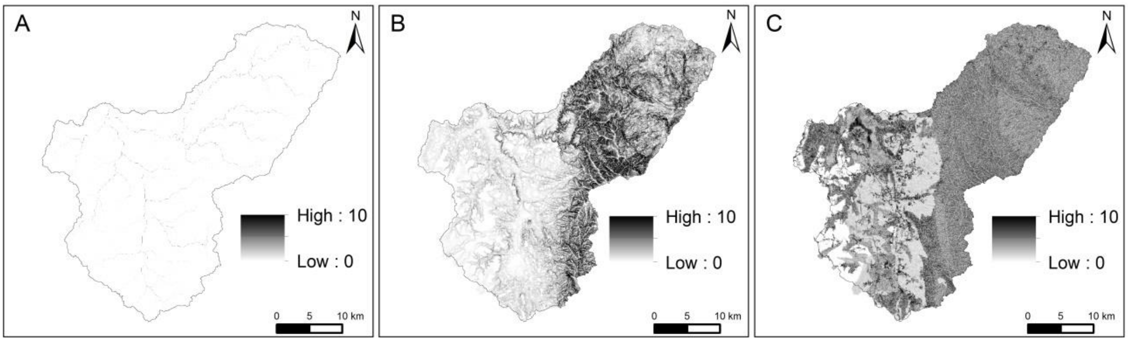

Figure 3 - Accumulated flow (A), average slope (B) and average relative permeability (C) in the Águeda basin.

3.3 Historical record of flood losses

A database of historical records of flood losses was compiled for the Águeda basin in order to validate the different combinations of weights (Reis 2011; Jacinto et al. 2014).

The used database was built during the DISASTER research project, (Zêzere et al. 2014) in which both authors participated. The nationwide DISASTER database comprises loss occurrences where human consequences were reported – those including death, injury, disappearance, evacuation and displacement of people – in newspapers. A complementary and local database was built during the project, which includes occurrences where uniquely material consequences are reported.

The database of historical records of flood losses for the Águeda basin is composed of 322 flood loss occurrences, spatially identifiable (Figure 4), registered in the newspapers between 1935 and 2010: 16 flood loss occurrences refer the above mentioned type of human consequences; 306 flood loss occurrences refer to floods that only caused material consequences.

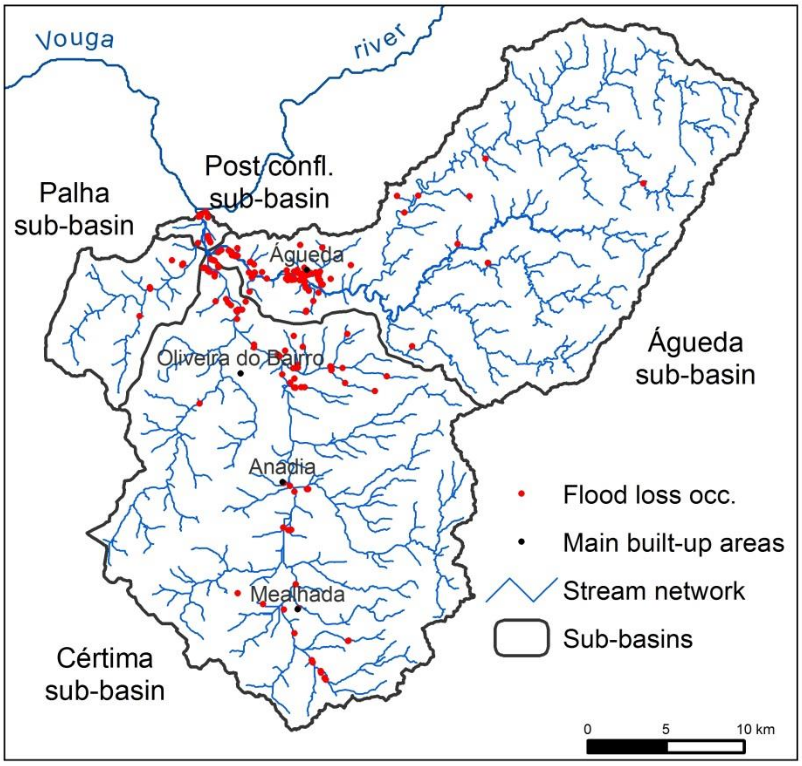

Figure 4 - Flood loss occurrences in the Águeda basin

The configuration of the occurrences leads to a division of the entire Águeda basin into 4 sub-basins for convenience of analysis: the sub-basin of the Águeda (425.8 km^2), the Cértima sub-basin (484.2 km^2), the sub-basin defined after the confluence of these two rivers (6.3 km^2) and the Palha sub-basin (63.0 km^2). Flood loss occurrences are clearly associated to exposure of human presence in built-up areas and activities in the floodplains, as the concentration of occurrences around the city of Águeda evidences. Although with approximate areas, the Águeda sub-basin presents a significantly higher number of loss occurrences than the Cértima sub-basin, particularly those translated in people evacuated and occurrences where only material losses are registered (Table 2). The 3 casualties are equally distributed by each of the considered sub-basins.

In this period, four flood severe events are reported in regard to the other flood events, in terms of human consequences and total number of occurrences:

- 18 January 1955: 1 death, 16 persons evacuated and 8 occurrences with only material consequences, all of them in the Águeda sub-basin;
- 25 December 1995: 43 persons evacuated and 25 occurrences with only material consequences. This event is interesting because only one occurrence is reported in the Cértima sub-basin, 3 in the post-confluence of the two major stream courses and none in the Palha sub-basin;
- 26 January 2001: 36 persons evacuated and 20 occurrences with only material consequences, 8 of them located in the Cértima sub-basin and 1 in the post-confluence;

- 2 January of 2003: 12 persons displaced and 32 occurrences with only material consequences, 14 of them located in the Cértima sub-basin and 2 in the post-confluence.

The 8 floods loss occurrences reported in the Palha sub-basin didn't occur in any of these major flood events, but are divided in four minor events with only material consequences, mostly road traffic interruptions. It is also interesting to note that the last of the three reported casualties have occurred in 1963.

Table 2 – Typology of flood loss occurrences in the Águeda basin, 1935-2010.

Sub-basins	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Águeda	10	190	200	1	0	0	106	6
Cértima	5	83	88	1	0	0	11	12
Post confluence	1	25	26	1	0	0	0	0
Palha	0	8	8	0	0	0	0	0
Total	**16**	**306**	**322**	**3**	**0**	**0**	**117**	**18**

(1) nº of occurrences with human consequences; (2) nº of occurrences with only material consequences; (3) nº of occurrences with human and material consequences; (4) nº of casualties; (5) nº of missing persons; (6) nº of injured persons; (7) nº of evacuated persons; (8) nº of displaced persons.

3.4 Weighing of flood susceptibility factors with the historical flood data

Based on previous assessments of stream susceptibility to flooding referred to in Section 1, it is known and assumed, *a priori*, that accumulated flow should be given the highest weight, starting with values around 60%, and the other two factors should be given smaller and approximate weights. In total, 11 combinations of weights were tested (Table 3). The table also presents the raster values under which SFS would not be represented. This procedure aims at excluding the values of susceptibility that are located in slopes and hilltops. In order to keep uniformity in the definition of susceptibility, the values' excluding limits vary, which also implies that the resulting length of streamlines in each of the combinations is not constant. In return, the number of occurrences covered by each combination of weights is also variable (cf. Table 4).

The number of flood loss occurrences that are located in streams or areas not covered by the resulting classes of susceptibility, after applying the excluding limits, are also considered as a criterion to select the best combination of weights (Table 4). As observed, the combination of weights that shows higher correlation with the location of reported flood losses is that of 80% for flow, 15% for slope and 5% for relative permeability. Nevertheless, the combination adopted was that of 85% for flow, 5% for average slope and 10% for average relative permeability because, although a slightly lower correlation coefficient, it is the combination that includes more flood loss occurrences. In fact, none of the Pearson correlation coefficients are higher than 0.6 so that this criteria was considered not as relevant as the percentage of past flood loss records covered by the resulting SFS.

After deciding about the final result of SFS – where uniformity in the decision process was assured through the exclusion of slope and hill top areas – the excluding limit of the selected combination (f85s05p10) was lowered from 1.20 to 1.00 in order to increase the stream network covered by the SFS assessment and, consequently, to include more flood loss occurrences. This procedure resulted in the inclusion of 4 more occurrences. Finally, susceptibility to flooding in each stream is classified using natural intervals in six classes.

Table 3. Combinations of the three factors and excluded values for the definition of streams' flood susceptibility.

Combinations tested*	Weights			Flood susceptibility excluded values
	Acc. Flow (Af)	Aver. Slope (As)	Aver. Relative Permeab. (Arp)	
f60s20p20	0.60	0.20	0.20	<3.10
f65s15p20	0.65	0.15	0.20	<2.68
f65s20p15	0.65	0.20	0.15	<2.80
f70s15p15	0.70	0.15	0.15	<2.30
f75s10p15	0.75	0.10	0.15	<1.90
f75s15p10	0.75	0.15	0.10	<2.00
f80s10p10	0.80	0.10	0.10	<1.60
f80s05p15	0.80	0.05	0.15	<1.65
f80s15p05	0.80	0.15	0.05	<1.74
f85s05p10	0.85	0.05	0.10	<1.20
f85s10p05	0.85	0.10	0.05	<1.25

* f = flow accumulation; s = slope; p = relative permeability

The final score in each combination results from the application of the following formula:

$$SFS = Af * w_{Af} + As * w_{As} + Arp * w_{Arp} \qquad \text{(Eq. 3)}$$

in which w_{Af}, w_{As} and w_{Arp} are the weight factors applied to each of the flood susceptibility factors (the sum of these weight factors is 1). The results obtained from the several tested combination of weights are compared with the flood loss database. The validation is performed not distinguishing between the two types of occurrences – those with human consequences and those with only material consequences – because every occurrence counts as testimony of a given flood event in time and space, independently of its severity. Pearson correlation coefficients between the occurrences found in each of the six classes of susceptibility for each combination of weights are calculated.

Table 4. Flood loss occurrences by class of susceptibility in each of the 11 combination of weights tested.

		Experimented combination of weights*										
SFS class		f60s20p20	f65s15p20	f65s20p15	f70s15p15	f75s10p15	f75s15p10	f80s10p10	f80s05p15	f80s15p05	f85s05p10	f85s10p05
1		7	0	3	0	7	0	6	6	0	9	6
2		10	4	10	0	0	1	1	1	1	4	1
3		1	7	5	4	4	3	4	4	3	4	4
4		9	10	33	17	17	17	17	17	17	17	17
5		200	210	179	193	213	193	192	192	192	199	192
6		29	29	29	46	26	46	47	47	47	40	47
Total occ.		322	322	322	322	322	322	322	322	322	322	322
Occ. out of model	No.	66	62	63	62	55	62	55	55	62	49	55
	%	20.50	19.26	19.57	19.26	17.08	19.26	17.08	17.08	19.26	15.22	17.08
Pearson Correl. Coef.		0.474	0.498	0.525	0.583	0.481	0.582	0.570	0.570	0.586	0.527	0.570

* f = flow accumulation; s = slope; p = relative permeability

4. Results

4.1 Stream flood susceptibility (SFS)

Susceptibility of stream to flooding is classified by descending order in 6 classes, i.e., class 6 represents the highest susceptibility. The resulting SFS identifies only the main stream lines in each of the four sub-basins of the entire Águeda river basin (Figure 5). Values of SFS range from 1.00 to 9.16. Classes of SFS are distributed as follows (cf. with Table 5):

- Class 6 [4.71-9.16]: the highest susceptibility to flooding is found in the post confluence stream of the Cértima and the Águeda sub-basins, and in the initial 1.55 km reach of the Cértima river;
- Class 5 [3.70-4.71[: this class is particularly relevant in the Águeda sub-basin as it crosses most of the low-lying areas of the Meso-cenozoic formations in this sub-basin. In the Cértima sub-basin, class 5 of susceptibility corresponds approximately to the natural lagoon named "Pateira de Fermentelos";
- Class 4 [2.73-3.70[: this class is absent in the Águeda sub-basin although it is relevant in the Cértima sub-basin, crossing relevant built-up areas between Oliveira do Bairro and Anadia;
- Class 3 [1.80-2.73[: length of streams with class 3 in the Cértima sub-basin is only 4.22 km. This class marks the entrance in the mountainous sector of the Águeda sub-basin where built-up areas along the main streams are practically residual;

- Class 2 [1.15-1.80[: class 2 sums almost 1/3 of all the SFS classified network (63.09 km). With the exception of the stream located north of built-up area Mealhada – which does cross urbanized areas –, the majority of the remaining streams run through agricultural, natural and forested areas;
- Class 1 [1.00-1.15[: In total, class 1 of SFS accounts for approximately 25% of the entire classified network. This is the unique class of SFS that is found in the Palha sub-basin.

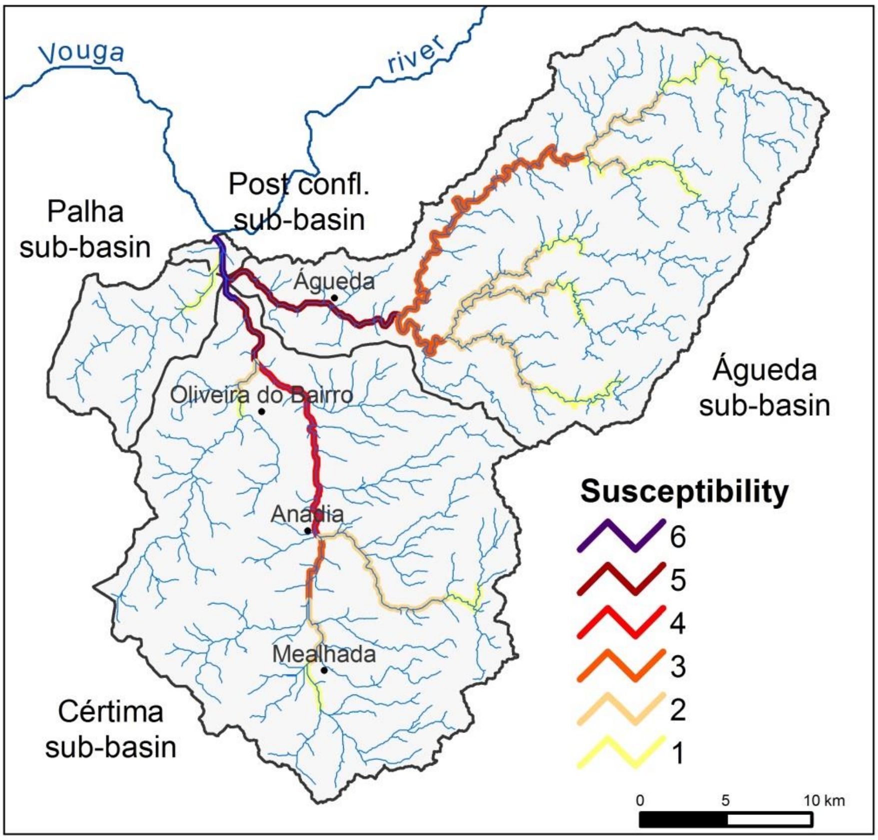

Figure 5 – Stream flood susceptibility in the Águeda basin.

Considering only the major sub-basins, the SFS classified network is comparatively more developed in the Águeda sub-basin (0.29 km/km^2) than in the Cértima sub-basin (0.11 km/km^2), although the area of the Cértima sub-basin is slightly bigger (484.2 km^2) (Table 5). This difference may be caused by the contribution of slope and permeability both to the development of the stream network and to the increase in susceptibility.

The pondered average of SFS, using length as the weight factor, for the four sub-basins results as follows: Águeda sub-basin (2.32), Cértima sub-basin (2.83), post-confluence sub-basin (6) and Palha sub-basin (1).

Table 5. Length of stream flood susceptibility classes in the main sub-basins of the Águeda river basin.

	Length by SFS class (km)						Total (km)	Area (km²)	Stream density (km/km²)
Sub-basins	**1**	**2**	**3**	**4**	**5**	**6**			
Águeda	32.36	44.09	33.10	0.00	12.97	0.00	122.52	425.8	0.29
Cértima	8.48	19.00	4.23	12.82	5.00	1.55	51.08	484.2	0.11
Post confluence	0.00	0.00	0.00	0.00	0.00	2.55	2.55	6.3	0.40
Palha	3.28	0.00	0.00	0.00	0.00	0.00	3.28	63.0	0.05
Total (km)	**44.12**	**63.09**	**37.33**	**12.82**	**17.97**	**4.10**	**179.43**	**979.3**	**0.18**

4.2. Relation between SFS and flood loss occurrences

Flood loss occurrences explained by the model

277 of the 322 flood loss occurrences (86%) are located close to the streams identified as the most susceptible to flooding – SFS class 1 to 6 – in the Águeda river basin (Table 6). Most of the occurrences are located at or nearby the city of Águeda (Figure 4 and Figure 6), whose main stream – the Águeda river itself – is classified with the class 5 of SFS, the second highest class of flood susceptibility. From the reported 117 evacuated persons in the period 1935-2010, 103 live in the city of Águeda and it is also here, associated with the class 5 of flood susceptibility, that the majority of occurrences where no human consequences are found (Table 6).

Table 6. Correspondence between flood losses and classes of stream flood susceptibility.

SFS class	(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	45	41	2	0	0	1	12
1	7	7	0	0	0	0	0
2	7	7	0	0	0	0	0
3	6	5	0	0	0	4	0
4	19	18	0	0	0	6	0
5	197	188	0	0	0	106	6
6	41	40	1	0	0	0	0
Total	**322**	**306**	**3**	**0**	**0**	**117**	**18**

(1) nº of occurrences; (2) nº of occurrences with only material consequences; (3) nº of casualties; (4) nº of missing persons; (5) nº of injured persons; (6) nº of evacuated persons; (7) nº of displaced persons.

A closer look at the relationship between the record of flood losses and the length of the SFS network allows to verify that some classified reaches, other than that one related to the city of Águeda, gain a relative importance (Table 7), for example, the SFS class 6 in the Cértima sub-basin and in the Post-confluence sub-basin in regard to the number of occurrences, and the SFS class 3 in the Cértima sub-basin in regard to the number of evacuated persons.

Table 7. Flood losses by SFS class, by sub-basin, relative to the length of the classified stream network

SFS class	Sub-basin	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	Águeda	32.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cértima	8.48	0.35	0.35	0.00	0.00	0.00	0.00	0.00
	Post confl.	-	-	-	-	-	-	-	-
	Palha	3.28	0.91	0.91	0.00	0.00	0.00	0.00	0.00
2	Águeda	44.09	0.07	0.07	0.00	0.00	0.00	0.00	0.00
	Cértima	19.00	0.21	0.21	0.00	0.00	0.00	0.00	0.00
	Post confl.	-	-	-	-	-	-	-	-
	Palha	-	-	-	-	-	-	-	-
3	Águeda	33.10	0.06	0.06	0.00	0.00	0.00	0.00	0.00
	Cértima	4.23	0.95	0.71	0.00	0.00	0.00	0.00	0.95
	Post confl.	-	-	-	-	-	-	-	-
	Palha	-	-	-	-	-	-	-	-
4	Águeda	-	-	-	-	-	-	-	-
	Cértima	12.82	1.48	1.40	0.00	0.00	0.00	0.00	0.47
	Post confl.	-	-	-	-	-	-	-	-
	Palha	-	-	-	-	-	-	-	-
5	Águeda	12.97	14.03	13.34	0.00	0.00	0.00	0.46	8.17
	Cértima	5.00	3.00	3.00	0.00	0.00	0.00	0.00	0.00
	Post confl.	-	-	-	-	-	-	-	-
	Palha	-	-	-	-	-	-	-	-
6	Águeda	-	-	-	-	-	-	-	-
	Cértima	1.55	10.32	10.32	0.00	0.00	0.00	0.00	0.00
	Post confl.	2.55	10.20	9.80	0.39	0.00	0.00	0.00	0.00
	Palha	-	-	-	-	-	-	-	-

(1) Length (km); (2) nº of occurrences per km; (3) nº of occurrences with only material consequences per km; (4) nº of casualties per km; (5) nº of missing persons per km; (6) nº of injured persons per km; (7) nº of evacuated persons per km; (8) nº of displaced persons per km.

Flood loss occurrences outliers to the model

Disasters occur where people reside or where people's activities take place. This fact implies that a classification of stream susceptibility to flooding may not necessarily correlate significantly with a given historical record of losses. As Table 6 shows, 45 of the 322 flood loss occurrences are outliers of the flood susceptibility results. In 41 of those 45 occurrences, only material losses were registered: 12 occurred in the Águeda sub-basin, 24 in the Cértima sub-basin and 5 in the post confluence sub-basin (Figure 6). All these occurrences are associated to a stream line, although of small hierarchy. The majority of damages consists of road (21 occurrences) and railway (2 occurrences) service disruptions, where the infrastructures cross the streams. Minor damages in houses and agriculture land are also reported.

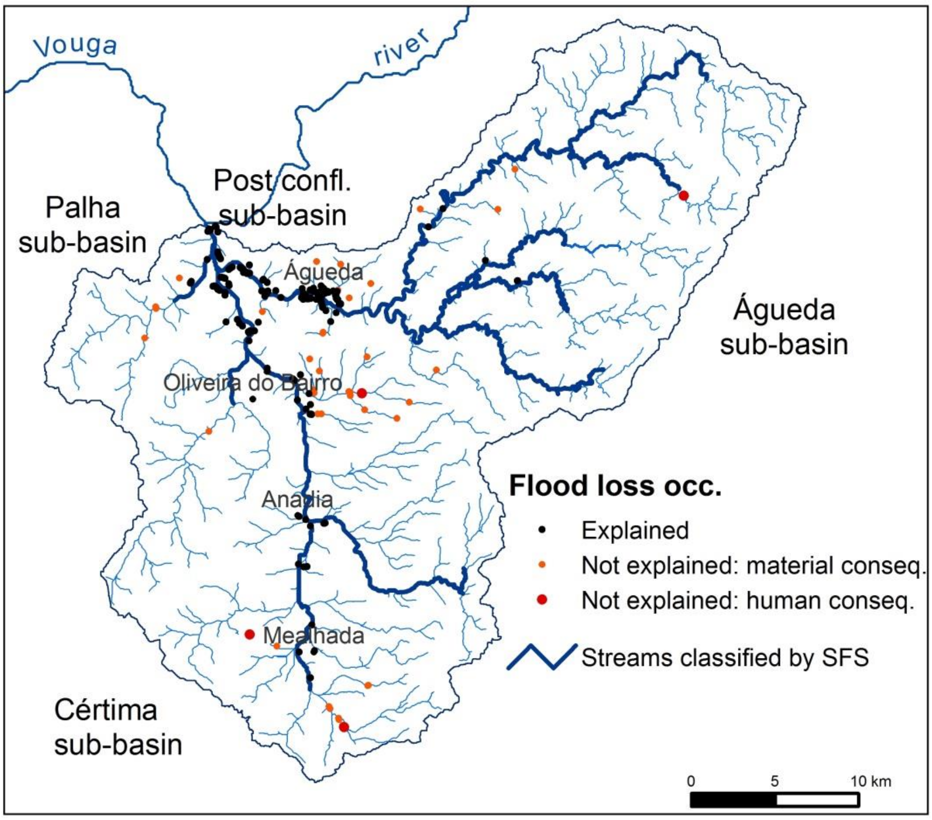

Figure 6 – Outlier historical flood loss occurrences

Other factors than the natural propensity of streams – and respective upslope areas – to flooding are triggering the occurrence of losses in areas not explained by the applied model. A more detailed analysis of the occurrences with human consequences that are outliers to the SFS classification is now provided. The referred 4 occurrences have resulted in the following human consequences: 2 casualties, 1 person evacuated and 12 displaced persons. In which contexts did these disasters took place? A consultation to the newspapers and respective database record allows observing that some of these losses are due to specific causes, without an unequivocal relation with a flood event. One of the casualties occurred in the upstream sector of the Águeda sub-basin. This occurrence is nearly covered by the model. The disaster took place when a 12 year girl was crossing the stream when backing home from school. The incident is framed in the flood event of 18 January of 1955, one of the most severe that had occurred in the 75 year period of the database. The newspaper report, however, is not clear whether the particular stream where the casualty took place was in a flood situation or not. The second casualty not covered by the model took place west of the Mealhada built-up area in the Cértima sub-basin, in December of 1935. No other occurrences are registered in this date in the Águeda basin, although floods losses, including casualties have occurred in other adjacent basins, such as the Mondego river basin. The newspaper report is vague only mentioning the victim was a 45 years old woman. The person evacuated is a 6 year old girl rescued from a tree where she was imprisoned by the flood flowing waters. It took place in a small village along the Cértima river. It is the unique disaster reported in the entire Águeda basin although several other disasters are reported in other neighbor basins. Finally, the 12 displaced persons occurred in a small built-up named Aguada de Cima, located in the Cértima sub-basin. This flood disaster is not associated with the Cértima river but with a smaller stream which crosses that village, and whose upstream area defines a 15 km^2 basin. This disaster is part of one of the four major flood events in the study area, 2 January 2003 (cf. section 3.3).

In general, along with these descriptions of losses, a flood hazard manifestation is identifiable. Nevertheless, frequently, the cause of the disaster is a circumstantial accident that could be eventually avoided. With effect, only one of the three reported casualties occurred in streams prone to flooding, i.e., those classified by SFS.

Regarding the occurrences with only material consequences, since they are occurring in streams which wouldn't be *a priori* among the most naturally prone to flooding, their location may reflect local critical conditions (e.g. in regard to road interruptions) eventually easily solved with local measures.

5. Discussion

Flood susceptibility is not equally represented between the two main sub-basins: the Águeda sub-basin, for example, displays an extensive class 5 of SFS – with a vast steep and impervious upstream area in the mountainous context of the Hesperian Massif – coinciding with the presence of the most important city in the study area; the stream network of the Cértima sub-basin develops in a narrower elevation amplitude, hilly morphology and more permeable geologic formations, although exposure is also significant due to the overlay and proximity of several human settlements with streams and their respective floodplains. Such difference between the two sub-basins must at least partly explain the fact that 24 of the flood loss occurrences not covered by the model are located in the Cértima sub-basin, while only 12 of those occurrences are located in the Águeda sub-basin.

It was noticed that certain SFS classes are particularly unevenly distributed through the Águeda river basin – for example, the absence of the SFS class 4 in the Águeda sub-basin. This is a consequence of (i) applying the same classification method to the entire basin and (ii) the existence of significant and sudden changes in flood susceptibility in specific reaches of the stream network, which in both cases may point future lines of research.

Results showed that there isn't a clear correlation between the natural susceptibility of streams to flooding and the location of the historical record of flood loss occurrences. On the other hand, the absence of disasters in the streams where the calculated flood susceptibility is higher does not mean that, when disasters occur upstream, such streams are not in situation of flooding. By the contrary, since they are located in the downstream sectors of the floodplain, it is very likely that they will also be flooded although that is not reported in the news. One of the possible conclusions to take here is that peoples' knowledge and memory about the hydrological behavior of the rivers may be preventing more disastrous consequences, as floodplains are mainly occupied with flood compatible uses such as agriculture. On the other hand, where flooding is less frequent and the behavior of streams less predictable, residential sprawl and other human type of settlements are displayed in floodplains and affected by flooding.

In the study area, small disasters – as well as 2 of the 3 reported casualties – are occurring in small streams, not explained by the model. The hydrographic contexts where these losses occur appear to be more related to flash flood events and critical runoff points, than to progressive floods because the contributive watersheds of such streams aren't competent to generate this later type of flood. The capacity to interpret the historical record of flood losses from the display of the physical factors that express the propensity to flooding is a relevant outcome of the applied methodology. In fact, many flood occurrences couldn't be explained by the SFS, and thus, other causes need to be identified. The evidence of such places is also a relevant sub-product of the SFS methodology.

6. Final notes

This paper described the application of a methodology for the assessment of flood susceptibility at the basin scale. The calculated SFS expresses a pre-condition to flooding based on three predisposing factors – flow accumulation, slope and permeability – where only the last one, by including land use, is potentially modifiable by human action. The methodology includes an analysis of the relation – or its absence – between the susceptibility results and the historical records of flood events. Moreover, due to the completeness of the used flood loss database, it was possible to comparatively analyze the resulting classes of flood susceptibility in face of the severity of flood losses, divided in those that implied human consequences and those small disasters with uniquely material consequences.

The assessment of streams' flood susceptibility through this methodology is useful in distinct types of geographical contexts. In data-rich contexts, the conditioning factors used in this study - with the same or higher spatial resolution - or the inclusion of additional factors can be performed. Moreover, data-rich contexts frequently dispose of historical records which help in finding the most adequate weight combinations. On the opposite spectrum of data availability, even in data-poor contexts global land use databases and Digital Elevation Models exist from which conditioning factors can be extracted. In these contexts, loss data from newspapers may not be available, as other data sources should be attempted as validation data.

Future research should further explore the validity of the streams' flood susceptibility model in face of the different hydrological triggering factors (e.g. prolonged rainfall events, strong convective weather), making use of a cross-analysis of the historical flood loss records and the rainfall patterns extracted from rain gauge stations.

The described methodology can be particularly useful and replicated in the context of regional and urban development plans where scientific input data to run hydrologic and hydraulic models is scarce. By providing data on flood susceptibility, confronted and validated with the historical record of flood damages, this study provides a preliminary assessment (cf. "Floods" Directive 2007/60/CE) which helps decision making in finding the specific arrangements that societies must put in place to manage flood disaster risk, i.e., to put in place appropriate flood risk governance strategies.

Acknowledgements

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Natural Hazards and Earth System Sciences

Comparing historical-hydrogeomorphological reconstitution and hydrological-hydraulic modelling in the estimation of flood-prone areas – a case study in Central Portugal

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Abstract. The Arunca River basin in Central Portugal has a historical record of hazardous events related to floods, causing widespread disturbance. This article describes the application of two approaches based on well-known methods for the estimation of flood-prone areas: (i) historical-hydrogeomorphological reconstitution, applied to the entire Arunca River basin, and (ii) hydrological-hydraulic modelling, applied to four sections selected from different (upper, middle and lower) sectors of the basin and including urban and rural areas along the Arunca River. The mapping of the flood-prone areas obtained by these two methods was compared in order to identify the main differences and similarities. Human interventions (river channel and floodplain morphological changes) were found to be the main factor explaining the differences and similarities between the results obtained by both methods. The application of hydrological-hydraulic modelling proved important in reinforcing the results of the historical-hydrogeomorphological method; it also helped in complementing the results produced by the latter method in urban areas and in areas with insufficient historical records. The application of the historical-hydrogeomorphological method, in turn, allowed for the size of the flood-prone areas to be determined where the primary data (e.g. geometry, roughness and flow) was not accurate enough for hydrological-hydraulic modelling. The methodological approach adopted demonstrates the strong complementary relationship between the different existing methods for estimating flood-prone areas, and may be reproduced for other drainage basins.

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1 Introduction

River floods, associated with social and economic damage and loss (UNISDR, 2009), are a major concern in many regions of the world and have been featured in a statement on scientific strategies and public policy management (USGS, 2007; IFRCRCS, 2009). In Europe, these hazardous processes have become one of the topics in land use planning, public policies for risk prevention and reduction, and early warning and emergency measures and resources (Coeur and Lang, 2008; Kubal et al., 2009; Merz et al., 2010).

The evaluation of flood-prone areas using a comprehensive modelling approach commonly targets the performance of different methods and models, with implications for spatial display (Casas et al., 2006; Fewtrell et al., 2008; de Moel et al., 2009). Frequently, the lack of available data sets and accurate flow geometry and dynamics presents new challenges for the design and calibration of hydraulic flood models. Several attempts have focused on transferring hydrological outputs to hydraulic models (Benito et al., 2003; Neal et al., 2009; Gül et al., 2010).

The use of historical data for past floods has been cited in different studies as an improvement on the uncertainty of extreme events (Barriendos et al., 2003; Coeur and Lang, 2008; Sudhaus et al., 2008) and hydrogeomorphological reconstitution has made descriptions of anthropogenic flood control possible (Spaliviero, 2003; Forte et al., 2005; Nirupama and Simonovic, 2007). These approaches and resources have also been used to support hydrological and hydraulic calculations (e.g. Ballais et al., 2005; Vijay et al., 2007; Apel et al., 2009; Neal et al., 2009).

The need to make use of historical data and/or hydrogeomorphological reconstitutions of past flood events to support the modelling of hydraulic flow is often the result of

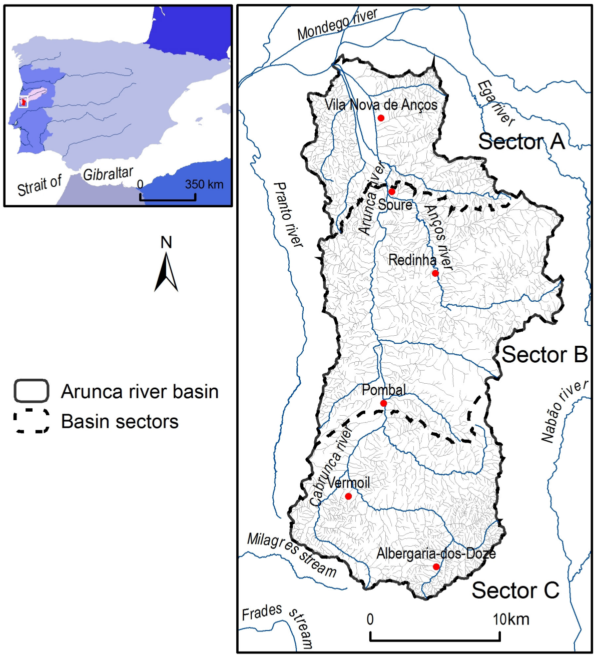

Fig. 1. Location of the Arunca River drainage basin (Central Portugal) and basin sectors.

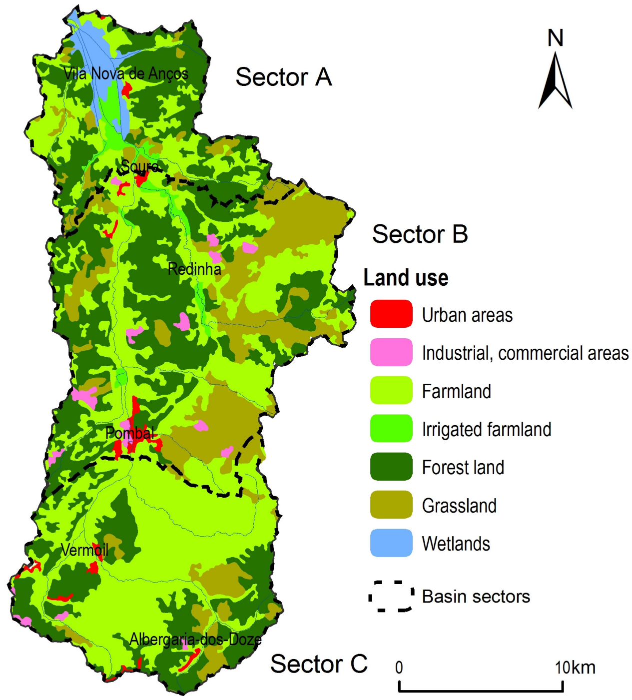

Fig. 2. Arunca River basin land use.

insufficient information for model calibration, due to a lack of peak discharge, channel geometry and roughness data.

This paper deals with two different methodological approaches to flood dimensions – the historical reconstitution of past events associated with hydrogeomorphological conditions, and hydrological-hydraulic modelling. This integrated analysis has made flood risk assessment possible with reinforced data and quality control for cartographic output. Cross checking was carried out, focussing on a reliable definition of flood impacts in a local context, which has been the goal of different authors and case studies (Nirupama and Simonovic, 2007; Barroca et al., 2006; Spaliviero, 2003; Kubal et al., 2009).

In this study, different resources and methods were applied to a Portuguese drainage basin in order to obtain an estimate of the flood-prone area by: (1) field work reconstitution of past events involving the collection of historical data and hydrogeomorphological analyses and (2) hydrological-hydraulic simulation of four sections of the same basin area for which accurate topographic data was available.

The aim of the study was to estimate the flood-prone areas in a small drainage basin using two different methodological approaches, to compare their cartographic outputs and to evaluate the reproducibility of these complementary methods.

2 Study area

The study area is located in Central Portugal (Fig. 1) and lies within the parallels 40°09′14″ N and 39°46′33″ N and the meridians 8°43′06″ W and 8°28′18″ W. It corresponds to the Arunca River drainage basin, which is part of the Mondego River drainage basin. The main tributaries of the Arunca River, in terms of extent and constancy of flow, are the Anços River and the Valmar Stream on the right-hand bank and the Cabrunca River on the left-hand bank.

In geological terms, the Arunca drainage basin area includes sedimentary rocks – detritic rocks mainly from the Tertiary and limestone from the Jurassic. In the northern and western areas the outcropping rocks are predominantly detritic, whilst in the eastern area and part of the southern area of the basin limestone predominates. The altitudes in the basin range from 553 m in the eastern area (the geodesic vertex of Sicó) to almost three metres at the confluence with the Mondego River (the Arunca River mouth). The basin has a mean slope of about 11 % with a maximum value of 125 % in the area of the Sicó Calcareous Massif in the eastern area of the basin. From a hydrogeomorphological point of view the basin reveals contrasts: (a) the upstream valley presents moderate hills and a stream incision, (b) in the intermediate section, which is the most populated and urbanised area, the valley widens, has asymmetrical banks and the main stream begins to drain to the north and (c) in the lower course, still framed by asymmetrical banks, the valley is characterised by

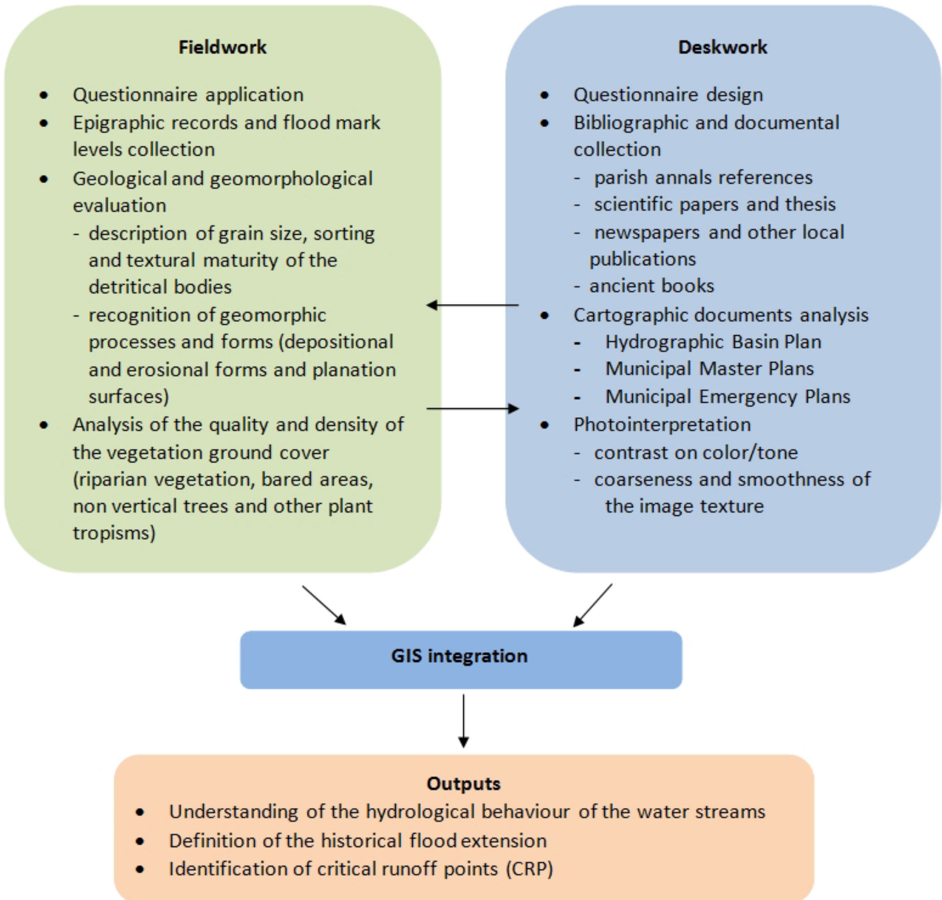

Fig. 3. Methodological approach for historical and hydrogeomorphological reconstitution.

a wide, flat plain extending to the confluence further downstream (Santos, 2009).

The area has a Mediterranean climate with hot summers and mild winters and a high orographic influence on rainfall (oceanic influences are revealed by rainfall, mainly in winter). The average monthly temperature ranges from 9 °C in January to 21 °C in August and the average annual rainfall is 964.6 mm (data from the series 1978/1979–2005/2006). The average monthly rainfall shows the contrast between the eastern area of the basin, with over 1200 mm yr^{-1}, and the western area, which has less than 900 mm yr^{-1}, mainly between October and January. Almost 20 % of the rainfall occurs in spring.

The main soil occupations (Fig. 2) are agricultural, with farmland and forest land occupying 42.9 % and 33.9 % of the total basin area respectively. The areas with a lower infiltration capacity correspond to only 2.5 % of the basin area and include urban, industrial/commercial and infrastructure areas. Wet zones, including areas used for growing rice, occupy a very similar area (2.1 %).

3 Methodology

Two different methodological approaches were used to estimate the inundated area of the Arunca River basin, which is frequently affected by floods.

The methodology was designed to deal with gaps in the primary data source and to obtain greater feasibility for the estimation of flood-prone areas.

3.1 Historical and hydrogeomorphological reconstitution

This analysis included historical and hydrogeomorphological methods which combined the collection of historical data relating to past events, a geological and geomorphological evaluation of the Arunca River basin following the case studies of Masson et al. (1996), Ballais et al. (2005), Coeur and Lang (2008) and Díez-Herrero et al. (2008), and a questionnaire administered to residents along the water streams in order to assess the flood hazard (e.g. Lastra et al., 2008). The basin area was subdivided into three sectors (A – downstream Soure, B – between Pombal and Soure and C – upstream

Pombal – see Fig. 1), an approach pointed out by Benito and Hudson (2010).

This method involved three main approaches: (i) field work, (ii) desk work and (iii) GIS integration, described below and summarised in Fig. 3. The first two approaches were performed simultaneously enabling the results to be integrated. This work took place from June 2007 to February 2008.

3.1.1 Fieldwork

A questionnaire was designed and administered to residents aged 18 or older living near the banks of the major streams of the basin and a final sample of 119 respondents was selected from the fieldwork. Along with this field inquiry, the authors gathered a total of 272 field notes. These records are intentional or purposeful ones with an exploratory objective. Nevertheless, considering an estimated population of 45 288 inhabitants, the confidence interval for this sample is 4.9 %, which means that the amount of field records collected is statistically strong.

The main groups of questions were designed to gather information on: (i) the limits of flood-prone areas, (ii) the maximum water column, (iii) land immersion time, iv) perceptions of the return period for major flooding, (v) evaluation of flow dynamics - from flash to progressive flood events, (vi) natural and anthropogenic triggering factors for floods and (vii) related damage and loss. A ratio of 1 questionnaire per 1.23 km of stream line was obtained.

All the questionnaires were geo-referenced for Geographic Information System integration using a GPS device (see examples in Fig. 4).

The fieldwork also involved the collection of nearly two hundred epigraphic records and flood high-water marks relating to past events over the entire Arunca River margin area and its tributaries (registered on bridges, houses, farm buildings, tree trunks and walls) cited by the local population. Most of these records refer to the flood of October 2006, the result of a 24 h rainfall of 104.8 mm, which is a value close to that estimated for the 100-yr return period (102.2 mm).

The fieldwork also enabled the analysis and interpretation of geomorphic forms and deposits associated with past floods. Sedimentary deposit outcrops (including a description of the grain size, sorting and textural maturity of the detritical bodies), identification of planation surfaces related to past floods events and incise channels eroded by torrential flows, enabled the recurring flood levels to be reconstituted. The sedimentary records were mapped and converted into digital data using a GIS support.

Analysis results of the quality and density of the vegetation ground cover ranged from riparian vegetation and bare areas associated with recent flash floods to leaning trees with identifiable impact marks. All this information was geo-referenced and converted into a digital format.

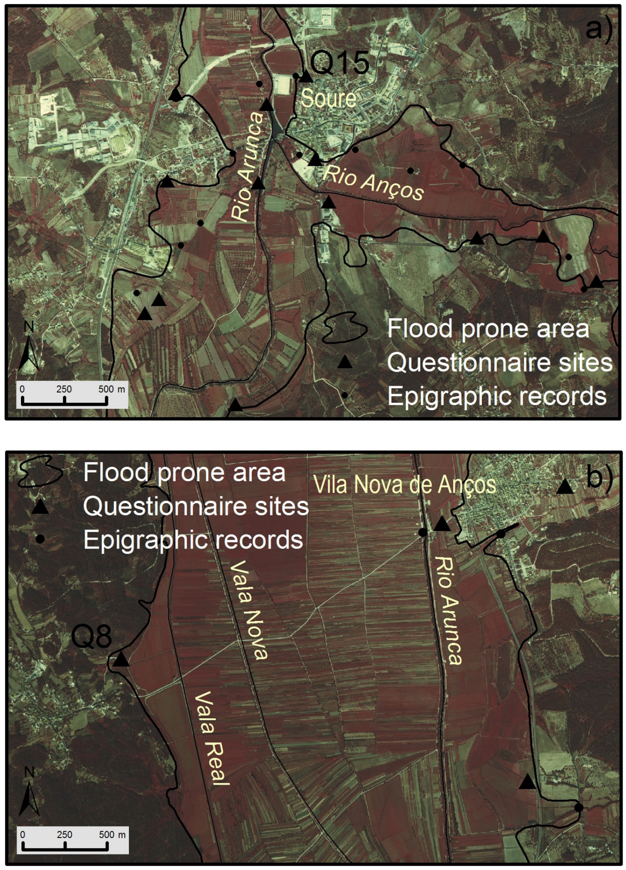

Fig. 4. Examples of field data collection. Water heights during last major flood event (2006) were 0.15 m in questionnaire site Q15 **(a)** and 1.5 m in Q8 **(b)**.

3.1.2 Deskwork

Primary sources were collected including references in parish annals, scientific papers and theses, newspapers and other local publications and old books. Historical records of past floods in newspapers and other media are scarce. The information collected related mainly to damage and loss associated with human life and property. The oldest publication describing the impact of flooding dated from the 18th century (Costa, 1712).

Several cartographic documents from different sources were collected, such as maps of flood areas included in the Mondego River Hydrographical Basin Plan – MRHBP (INAG, 2000) and partial cartographic outputs from municipal master plans and emergency plans. All the existing cartographic representations were mainly constructed on a 1:25 000 scale, and, in material terms, recognised the alluvial deposits as the limit of the flood-prone area.

Consistent photointerpretation was produced with digital aerial false colour imagery on a 1:15 000 scale, using the Portuguese Geographical Institute resources. The digital

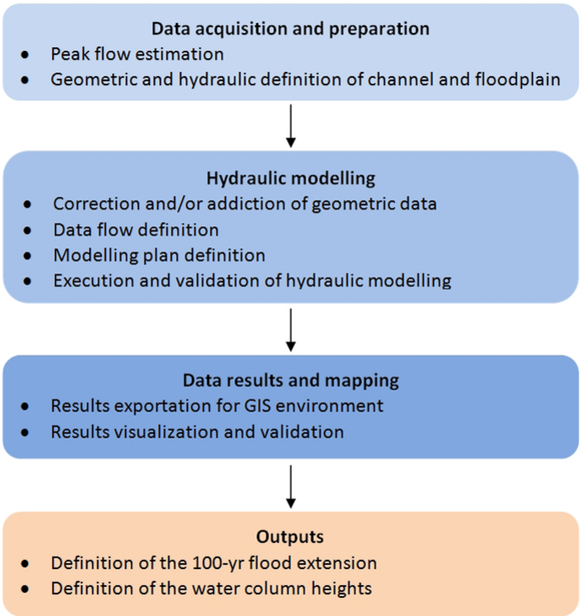

Fig. 5. Methodological approach for the hydrological-hydraulic method.

photography's sensitivity to green, red, and near-infrared radiation was particularly useful in delineating vegetation, wet soils and immature sedimentary deposits in the major stream valleys using colour/tone contrast, coarseness and smoothness of image texture.

As part of the deskwork, a Geographical Information System (GIS) was constructed, into which all the data collected from the fieldwork and deskwork was integrated, and then analysed using ESRI software ArcGIS and its 3-D and Spatial Analyst extensions. The GIS allowed for accurate and in-depth processing of the different sources of information, resulting in a definition of the maximum historical flood level.

The historical and hydrogeomorphological method resulted in two main outputs:

– the maximum historical flood extension, reported or collected as the wider inundated area, assumed to be the maximum fluvial flow for past events.

– a definition of critical runoff points (CRPs), consisting of locations where fluvial constraints, with or without associated damage, have been reported by the local population.

3.2 The hydrological-hydraulic method

The hydrological-hydraulic method was applied to four stream sections distributed along the Arunca River in order to map the 100-yr return period flood (see Fig. 6).

The hydrological-hydraulic method applied followed three main steps, as summarized in Fig. 5 and described in the following sections: (1) geometrical and flow data acquisition and preparation; (2) hydraulic modelling; (3) data results and mapping.

3.2.1 Data acquisition and preparation

Peak flow estimation

The Soil Conservation Service (SCS) method (see formulas in Table 1) was applied to estimate the 100-yr return period peak flow.

Rainfall intensity in $\mathrm{mm\,h^{-1}}$ (I) was obtained using the formula $I = aD^b$, in which D is the rainfall duration (min), assumed to be equal to the concentration time in each fluvial section, and a and b correspond to the parameter values for the Intensity-Duration-Frequency (IDF) curve, calculated and presented in the Mondego River Hydrographical Basin Plan (INAG, 2000): $a = 654.37$ and $b = -0.681$. The latter parameters result from the adjustment by the least-square method between rainfall intensity and duration associated with the 100-yr return period for durations of up to 24 h, as described in Brandão (1995). These procedures are referent to the nearest gauge station located in the city of Pombal using values from a 31 yr series. The adopted concentration time corresponds to the arithmetical mean for the values obtained using the Temez (1978), Chow (1964) and Soil Conservation Service (SCS, 1973) formulae (see formulas in Table 2). In Table 3 some intermediate parameter and final peak flow results are presented.

Geometric and hydraulic definition of channel and floodplain

Digital Terrain Models (DTM) for each section were obtained from maps on a scale of 1:2000 (2-m equidistant contours) and 1:10 000 (5-m equidistant contours). In addition to the hypsometric data obtained from the contours, these mapping sources also included hypsometric data from stream lines, roads and earthwork crests. Local data from aerial photographs, transversal sections, bridge profiles and field survey measurements were used to produce a more accurate morphological representation, involving better location and delineation of river embankments, bridges (including piers and decks) and railway levees.

After the DTM preparation in Triangulated Irregular Network (TIN) format, the ArcGIS extension HEC-GeoRAS version 4.2.92 (HEC, 2005) was used to extract the geometric and hydraulic elements required for subsequent hydraulic modelling (e.g. stream centerline, bank lines, cross sections, hydraulic structures and land use).

For each of the HEC-GeoRAS layers created, it was necessary to associate an attribute table containing information about its positioning along the cross-section. Finally, the geodatabase was exported in Extensible Markup Language (XML) format and, subsequently, in Spatial Data File (SDF) format so that it was readable in an HEC-RAS environment.

Table 1. Formulas for peak flow estimation using SCS method (from SCS, 1973).

Peak discharge (Q_p) in $m^3\,s^{-1}$	$Q_p = \frac{RA}{3.6T_c}$	R - depth of runoff (mm) A – drainage area (km^2) T_c – concentration time (minutes)
Depth of runoff (R) in mm	$R = \frac{(p-I_a)^2}{(p-I_a)+S}$ if $p > I_a$	p – depth of 24-hr precipitation (mm) I_a – initial abstraction (mm); ($I_a = 0.2S$) S – maximum storage (mm)
Maximum storage (S) in mm	$S = \frac{25\,400}{CN} - 254$	CN – Runoff Curve Number corresponding to wet soil condition (AMC III) obtained in GRID format from SNIRH (2007)
Depth of 24-hr precipitation (p) in mm	$p = D_p\left(\frac{I_p}{60}\right)$	D_p – rainfall duration in minutes I_p – rainfall intensity in $mm\,h^{-1}$
Rainfall intensity (I_p) in $mm\,h^{-1}$	$I_p = a\,(T_c)^b$,	a and b – parameters from the Intensity-Duration-Frequency (IDF) curves

Table 2. Formulas for concentration time estimation (from Temez, 1978; Chow, 1964; SCS, 1973).

Method	Formula	
Temez (T_cT) in hours	$T_cT = 0.3\left(\frac{L}{J^{0.25}}\right)^{0.76}$	
Ven Te Chow (T_cV) in minutes	$T_cV = 25.2\left(\frac{L}{\sqrt{J}}\right)^{0.64}$	
Soil Conservation Service (T_cSCS) in hours	Maximum storage (S) in mm	$S = \frac{25\,400}{CN} - 254$
	Lag time (T_l) in hours	$T_l = L^{0.8}\left[\frac{(0.03937\ S+1)^{0.7}}{734.43(D_{med})^{0.5}}\right]$
	$T_c\ SCS = 1.67T_l$	

Where: L is the main stream length in km; J is the main stream average slope in $m\,m^{-1}$ for Temez formula and in % for Ven Te Chow formula; D_{med} is the basin average slope in %; CN is the Runoff Curve Number.

Table 3. Parameters and results regarding peak flow estimation.

	Section/Sub-basins	CN (AMC III)	Area (km^2)	Mean T_c (hours)	R (mm)	Q_p ($m^3\,s^{-1}$)
1	Arunca River (upstream Vermoil)	86	64.55	4.16	34.85	135.88
	Small Arunca River tributary	89	0.78	0.66	15.62	4.58
2	Arunca River (upstream Pombal)	87	175.75	5.66	38.82	334.54
	Vale Stream (right tributary)	90	19.87	2.09	27.88	73.77
	Degolaço Stream (left tributary)	81	5.30	2.51	17.43	10.22
3	Arunca River (upstream Soure)	86	322.64	9.59	47.95	448.10
	Anços River (upstream Soure)	89	110.62	5.36	41.61	238.55
4	Arunca River (upstream Pt. Mocate)	88	469.80	10.41	54.09	765.92
	St. Isidro Stream (left tributary)	82	11.91	2.32	17.70	25.27
	S. Tomé Stream (1st right tributary)	82	5.57	2.45	18.36	13.65
	Sicó Stream (2nd right tributary)	82	6.19	1.96	15.91	13.93

Table 4. Geometric data in the four sections applications.

Section		Reach length (km)	Reach slope (m m^{-1})	# cross sections	Average equidistance (m)
1 – Ponte Vermoil		0.2	0.00594	30	7
2 – Pombal		2.5	0.00338	393	6
3 – Soure	Arunca River (upstream confluence)	1.1	0.00129	106	10
	Arunca River (downstream confluence)	0.9	0.00175	194	5
	Anços River	1.2	0.00078	166	7
4 – V. N. de Anços		3.5	0.00112	187	19

3.2.2 Hydraulic modelling

The 1-dimensional hydraulic modelling was performed with HEC-RAS software, version 3.1.3., designed by the Hydrologic Engineering Center of the United States Army Corps of Engineers (USACE), with RAS standing for River Analysis System (HEC, 2002a, b). The hydraulic modelling considered a steady and unidirectional flow. Computation between cross-sections was based on the solution of the 1-dimensional energy equation (HEC, 2002b).

The use of HEC-RAS tools can be subdivided into four phases: (a) correction and/or addition of geometric data for cross sections and hydraulic structures; (b) input of estimated peak flow data (for the main channel and its tributaries) and definition of boundary conditions (establishing the initial height of water), for which the normal depth slope method was selected using reach slope as a simplification of energy slope value as proposed in HEC (2002b). Observed flow data recorded at the Ponte Mocate gauge station was inserted in order to help calibrate the boundary flow conditions (see location in Fig. 8d and 9d); (c) general model plan definition – the geometry and flow data files previously prepared were assigned and a mixed flow regime was chosen; (d) execution and validation of hydraulic computations.

3.2.3 Data results and mapping

The computed 100-yr water surface profiles were exported to an HEC-GeoRAS- compatible format. Cross referencing this data with the DTM data in an ArcGIS environment enabled the flood extent and height mapping for the four fluvial sections modelled to be obtained.

3.2.4 Application areas

The 1-dimensional hydraulic model was applied to four sections of the Arunca River (Fig. 6): Sect. 1 (Ponte de Vermoil), Sect. 2 (Pombal), Sect. 3 (Soure) and Sect. 4 (Vila Nova de Anços). The sections were selected with the aim of covering the upper, middle and lower basin of the Arunca River, as well as urban and rural areas. However, the choice was strongly influenced by the availability of detailed cartography for the municipalities of Soure and Pombal (on a scale of 1:2000 for Sects. 1 and 2, and 1:10 000 for Sects. 3 and 4). Table 4 presents some geometric data for the modelled sections (application areas).

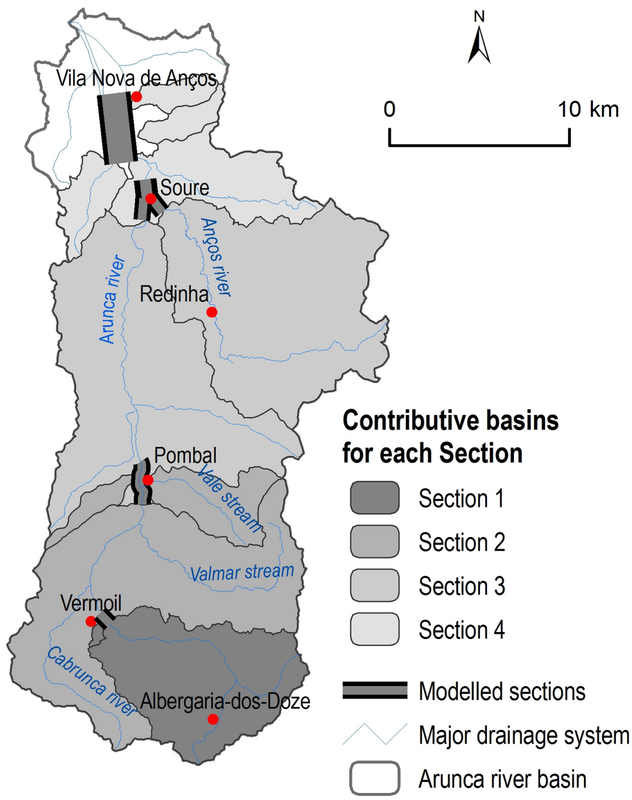

Fig. 6. Location of modelled sections and contributing drainage basins.

Section 1 corresponds to the smallest section modelled, located in the upper course of Arunca River, and is characterised by morphological changes associated with a bridge

Table 5. Flood-prone areas and number of critical runoff points (CRPs) in the Arunca basin.

Sector	Sector area (km^2)	Historic flood-prone area (km^2)	CRP
A – Downstream of Soure	110.75	17.24	32
B – Between Soure and Pombal	263.68	19.30	130
C – Upstream of Pombal	175.66	10.99	91
Total	550.09	47.53	253

Table 6. Water height for the flood-prone areas in the modelled sections

Height (m)		Area (%) < 1 m	1–2 m	2–3 m	3–4 m	> 4 m	Total Area (ha)
Section	1	79.81	13.14	5.11	1.70	0.24	4.1
	2	66.51	26.48	1.81	0.95	4.25	102.8
	3	9.54	17.45	33.58	34.10	5.33	193.4
	4	9.37	19.30	26.83	31.32	13.19	706.7

and a road landfill construction. In Sects. 2 and 3, the fluvial stream modelled corresponds mainly to the urban areas of Pombal and Soure, respectively. These two sections cover the areas with the highest anthropogenic changes in the channel, margins and floodplain. In Sect. 3, two main rivers (the Arunca and the Anços – an Arunca River tributary) converge in the urban area of Soure. Finally, Sect. 4 corresponds to the lower sector of the Arunca alluvial plain, where it can be seen that the Arunca River flows in the most elevated (eastern) part of the floodplain.

3.3 Comparison methodology

The application of the hydrological-hydraulic method enabled the historical-hydrogeomorphological mapping to be accredited with an approximate recurrence interval and possible flood extension differentiator factors to be identified.

The results of Sects. 2, 3 and 4 were divided into several 200-m long blocks (12, 13 and 18 blocks, respectively) in order to quantitatively analyse the flooded areas, whereas the area in Sect. 1 was smaller and allowed for direct comparison. The Pearson correlation coefficient between the flood-prone areas obtained from both methods (in Sects. 2, 3 and 4) was used to evaluate the spatial adjustment of the cartographic outputs.

4 Results and discussion

4.1 Results of historical and hydrogeomorphological methods

These methods enabled the representation of the historical flood-prone area based on past evidences, and the identification of a total of 253 critical runoff points (CRPs).

Most of the flood problems were related to flash flood events (97 % of the total questionnaires); in the urban areas most of the reported floods were the result of overbank flow, underdimensioned pluvial sewer networks and unchannelled superficial runoff over impervious surfaces. The flood-prone areas associated with high flow were mainly restricted to the alluvial plain (north of Soure), with a sea tide influence on flood episodes reported in areas near the Arunca River mouth. According to the questionnaires, the water column reported was extremely variable – higher values (> three meters) were reported in the alluvial plain near the river bed. The most frequently reported average immersion time was between one and six hours, with the most prolonged floods (> two days) reported almost exclusively in Sector A.

The maximum historical flood extension and mapping of critical runoff points for the three sectors are presented in Fig. 7. It can be seen that in the entire Arunca River basin the historical flood represents a flood-prone area of 47.53 km^2, corresponding to nearly 8.6 % of the total basin area (Table 5) and a total of 253 CRPs were identified.

Most of the CRPs were recorded in Sector B (between Pombal and Soure), due to the urban areas of Soure and Pombal. In Pombal there is a runoff problem associated with the sewage and rainfall drainage system and the underground

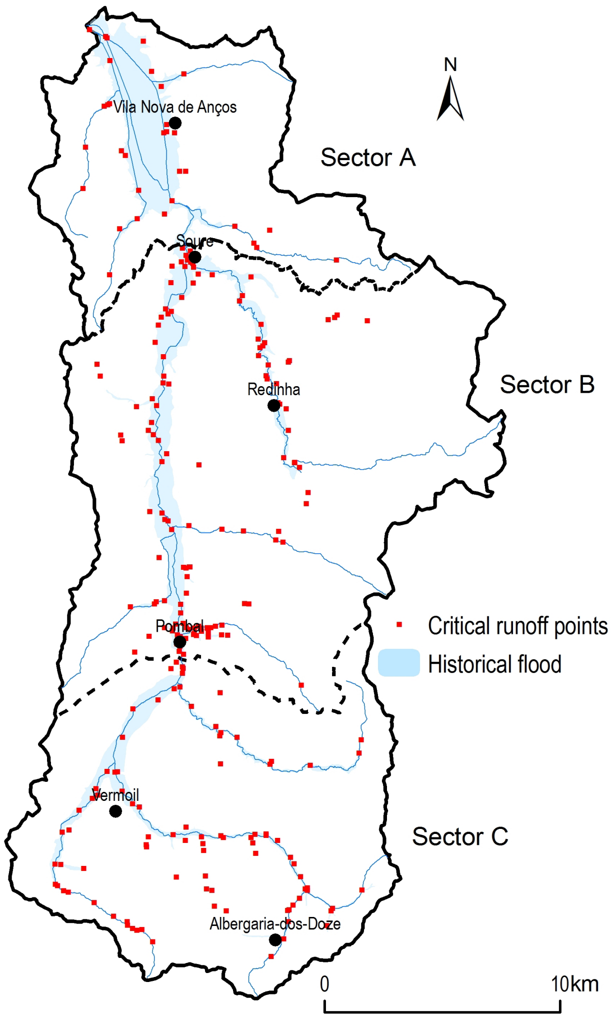

Fig. 7. Flood-prone areas and critical runoff points (CRPs).

drainage (with low flow section) of some water streams that cross the urban area. Some CRPs are related to an abrupt break in the longitudinal water stream profile. In Sector A (downstream of Soure), the CRPs are mostly associated with bridges and, in some cases, weirs.

4.2 Hydrological-hydraulic method results

The 100-yr flood maps resulting from 1-D modelling in HEC-RAS are presented in Fig. 8 for the four sections under consideration. The water height values for the flood-prone areas in each section are shown in Table 6.

In Sect. 1 most of the flooded area (79.81 %) presents a water height of less than one metre (Table 6); the areas with greater heights (>three metres) correspond to the Arunca channel bed. The bridge crossing the Arunca River in this section is submerged by an 11 cm water column over the bridge deck, and the road that crosses the floodplain on both

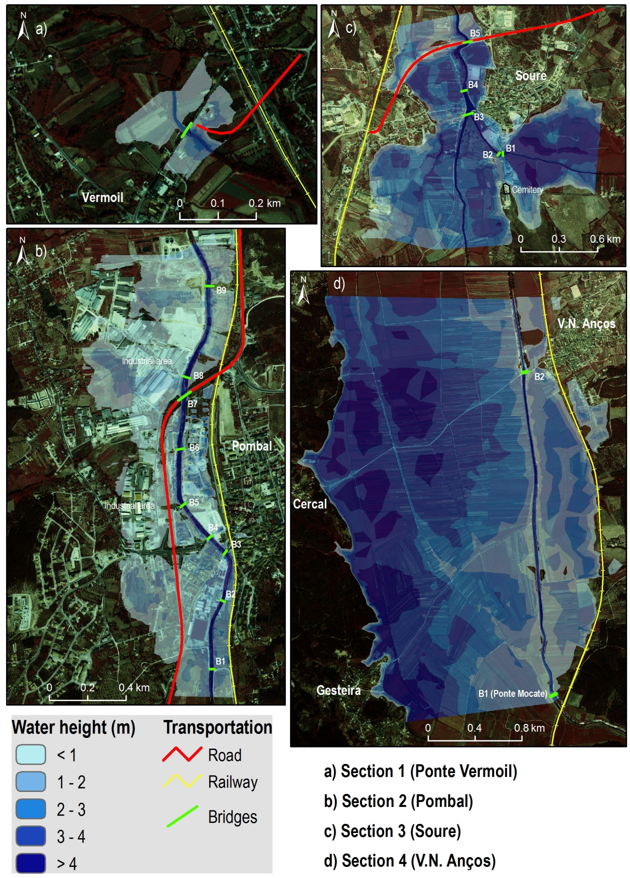

Fig. 8. Flood-prone areas and water height in the modelled sections.

sides of the bridge represents a clear obstacle to the flow, as can be seen in Fig. 8a.

In Sect. 2, the highest water column is around 5.5 m (see Fig. 8b), although the height of the flooded area is mainly less than one metre (Table 6). On the western side, the flood-prone area is more extensive, due to the larger dimensions of the left-hand bank of the Arunca River. On the eastern side of the area, the railway acts as a longitudinal embankment and prevents the flooding of some urbanised areas. In the central part of the modelled section, the existence of embankments prevents some areas from becoming flooded. Four of the nine existing bridges may be submerged (with 0.60 m to 1.60 m water columns over the bridge deck).

In Sect. 3 (Fig. 8c and Table 6), almost all the alluvial plain is flooded, with part of the historical urban area of Soure being exposed. It can be seen that most of the flooded area has a water column of over two metres, with some areas showing water heights of over six meters. The model indicates that three of the five existing bridges may be submerged (with 1.01 m to 3.10 m water columns over the bridge deck).The model also shows that a bridge (B5) obstructs the flow, imposing contrasting water column heights upstream and downstream of its location.

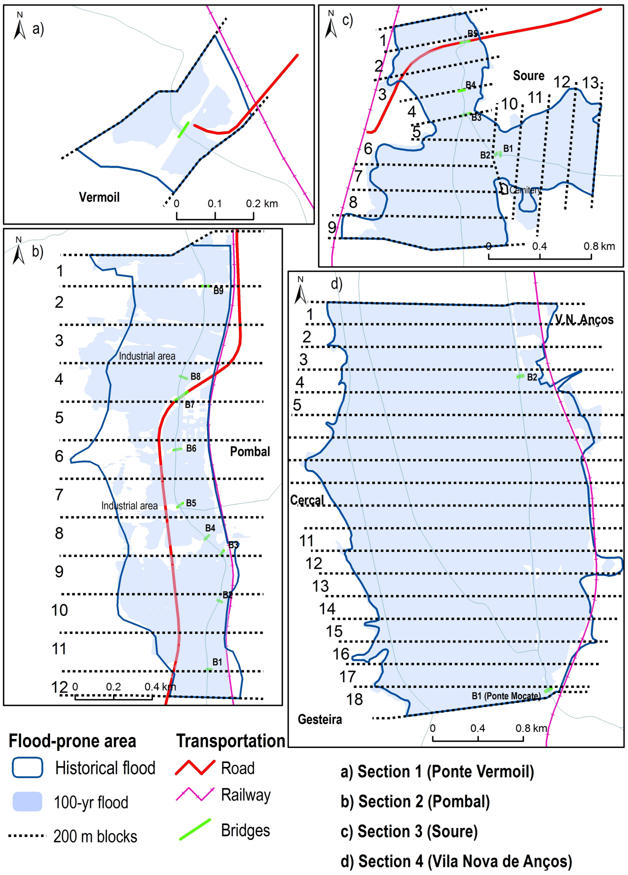

Fig. 9. Flooded areas in the modelled sections defined by both methods.

In Sect. 4, most of the flooded area involves water column heights of between three and four metres (Fig. 8d), corresponding to areas occupied by rice fields or permanently irrigated crops. The modelled results show that some roads crossing the alluvial plain will be submerged by a water column over three metres high and that the railway embankment acts as a restraining structure for flood expansion to the east. The asymmetric distribution of the water column heights can be verified, with areas of major water column height being located on the western side of the river bank, on the left-hand bank, and the lower heights contiguous to the Arunca River channel. This asymmetry is a consequence of the anthropogenic channelization of the Arunca River (previously flowing along the eastern side of the floodplain), which also determines the surge of inundated fields without any overbank flow for the Arunca River. In this section, one bridge (B2) may be submerged, with a 0.36 m water column above the bridge deck.

4.3 Comparison of results and discussion

The comparison of the results obtained by both methods is presented in Fig. 9 and Table 7 for each of the four sections defined. Figure 10 presents the scatter plot of the flooded areas obtained by both methods for the various blocks defined in Sects. 2, 3 and 4, and the corresponding Pearson correlation coefficients (R).

In Sect. 1 (Fig. 9a), the flooded areas obtained by the two methods are very distinctive. The hydrological-hydraulic method gives a total flooded area that is almost 47 % lower than the flooded area resulting from historical and hydrogeomorphological reconstitution. This is explained by the successive removal of weirs which restrict flow and the enlargement and excavation of the river channel over the last three decades. The results demonstrate that there is a close cause-effect response between the flood-prone area and river channel interventions in the upper sector of the Arunca River basin.

In Sect. 2 (Fig. 9b), the flooded area obtained from the historical and hydrogeomorphological reconstitution (the maximum historical flood) is nearly 20 % greater than the area obtained by hydrological-hydraulic modelling (the 100-yr flood), presenting values of 122.36 ha and 102.79 ha, respectively (Table 7). In Fig. 10–Sect. 2, it can be seen that the correlation between the flooded areas of the various blocks defined in this section is very weak (0.455). This is due to the diverging values of the flood-prone areas obtained in blocks 5 to 8, as the exclusion of these blocks reflects a correlation of 0.927 (see the dashed line in Fig. 10). It is explained by significant morphological changes in these blocks (enlargement and excavation of the river channel and embankments in the industrial area). The obstruction created by the railway in the eastern part of the floodplain is very evident in Fig. 9b.

In Sect. 3 (Fig. 9c), the flooded areas defined by the two methods are more similar than in the previous sections, totalling 183.49 ha for the historical maximum flood and 193.43 ha for the 100-yr flood. The figures for the flood-prone areas obtained by both methods are very similar in almost all the blocks, resulting in a correlation value of 0.959 (Fig. 10 – Sect. 3).

In Sect. 4 (Fig. 9d), the flood-prone areas obtained by both methods are even more similar, with the flooded area corresponding to the 100-yr flood in this section, being only 1 % higher than the corresponding total maximum historic flood: the correlation coefficient is 0.978 (Fig. 10 – Sect. 4). The greatest similarity between flood limits can be observed in the left-hand sector of the floodplain and may be explained by the fact that this margin has fewer tributaries and there is a clearer transition between the floodplain and the hillside.

The results show that the data obtained from the population survey, the reconstructions of paleo-hydrogeomorphological characteristics and the systematisation of epigraphic records have a good match for the flood-prone area obtained by hydraulic modelling for an estimated return period of 100 yr, during which the floodplain, in general, preserved its natural topography. This was to be expected due to the occurrence of recent flood episodes, well

Table 7. Values for the flooded areas (ha) in Sects. 1, 2, 3 and 4 obtained using the historical and hydrogeomorphological method (HHG) and the hydrologic-hydraulic method (HH) – total and for each 200 m block defined.

Section		1		2		3		4	
		HHG	HH	HHG	HH	HHG	HH	HHG	HH
	Total	7.74	4.10	122.36	102.79	183.49	193.43	714.25	706.66
Block	1			11.28	10.11	11.09	11.58	35.81	33.90
	2			9.95	9.91	14.19	13.79	37.61	34.73
	3			10.47	12.67	12.60	13.73	34.75	33.74
	4			10.78	11.31	8.70	8.87	36.69	36.59
	5			10.91	6.69	8.69	9.06	41.35	42.15
	6			12.52	5.88	15.67	17.03	45.04	46.33
	7			10.89	6.56	19.10	20.48	46.95	47.60
	8			10.83	7.12	17.78	20.23	47.93	48.54
	9			11.90	11.21	27.11	24.42	45.82	46.64
	10			10.51	10.26	7.62	9.16	43.61	43.65
	11			7.46	7.11	13.07	16.63	42.80	42.41
	12			4.85	3.96	13.82	14.19	46.88	43.79
	13					14.05	14.27	39.41	39.59
	14							38.16	38.47
	15							38.44	37.45
	16							36.24	34.51
	17							32.73	31.42
	18							24.03	25.15

recognized in the local context, and related to precipitation events with a return period of more than 100 yr.

The four sections tested showed that the greater the width of the valley and number of control blocks, the better the match for the results obtained by both methods. In fact, Sect. 1 produced the worst results since it contained only two cross sections and a narrower alluvial bottom, while Sect. 4 with 19 blocks and the greatest width in the valley, produced a better match between the methods (see Figs. 9 and 10).

The results show that the response to the delineation of the flood-prone areas using the two methods is favourable in cases where the floodplains are bounded by embankments on the side of the main channel, associated with the (rail or road) transport network. In cases where the presence of bridges and embankments creates bottlenecks in the normal flow, a good match is obtained when the alluvial plain is wider.

Both methods show similar results when there is a confluence of two rivers (Sect. 3), showing that the hydraulic modelling results are consistent with historical and paleo-hydrogeomorphological reconstruction data.

The hydrologic-hydraulic method of defining flooded areas is more accurate in areas featuring topographic changes caused by human intervention and also in areas where the modelling database contains more details (e.g. geometry, roughness and flow). In contrast, the historical-hydrogeomorphological method produces better results in wide areas of the valley, expressing extreme flow conditions. It can also be seen that this method can be generalised more easily for the whole basin, even though the database area is less reliable. In general, therefore, the study demonstrates that the historical-hydrogeomorphological method can easily be applied to the entire basin area, whilst the need for peak-flow, channel geometry and roughness data restricts application of the hydrological-hydraulic method. The importance of method complementarities should also be emphasised, especially in areas which lack data, in terms of the generalised application of the 1-D or 2-D hydrological-hydraulic approach.

5 Conclusions

With the historical-hydrogeomorphological method, the specific results for the area studied show a very significant flood-prone area in the Arunca River basin area, corresponding to almost 9 % of the total basin area and affecting the main urban areas located near water streams. The sections modelled using the hydrological-hydraulic method confirm the importance of the estimated inundated areas, and also clarify the significant impact on some urban areas with high water column values in the event of flooding (large submerged areas with depths of over 4 m were found, specifically in the urban areas of Pombal City and Soure Town). Both methods show the importance of the flood-prone areas regardless of the basin area that contributes with the flow, the morphology of the valley and the geometry and roughness of the channel.

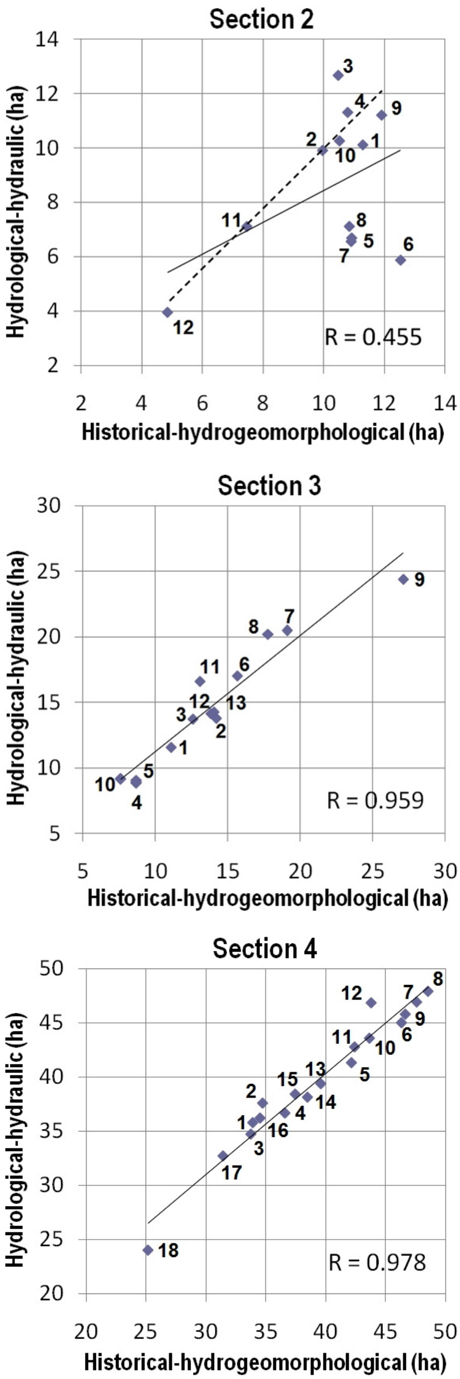

Fig. 10. Scatter plot of the flooded areas for Sects. 2, 3 and 4 obtained by both methods. *R* corresponds to the Pearson correlation coefficients (the dashed line in Sect. 2 represents the linear regression line excluding blocks 5 to 8).

As the historic flood-prone area reflects the hydraulic flow conditions prior to the anthropogenic changes to the Arunca channel, greater differences for the 100-yr flood-prone area appear when more changes are introduced due to anthropogenic influences. This leads to the conclusion that the hydraulic-hydrologic method is sensitive to geometric inputs and is valid whilst these morphological conditions remain in place. On the other hand, the historical and hydrogeomorphological method tends to be more independent of time and does not reflect recent morphological changes in the floodplain. This has clear implications for the temporal validity of both types of flood-prone mapping, emphasising the importance of their combined use.

The reproducibility of this comparative approach is demonstrated by the importance of flood-prone area estimation, particularly in assuring the reliability of the historical-hydrogeomorphological method or in dealing with missing or inconsistent data used in hydrological-hydraulic modelling.

The complementarities of the methods made it possible to estimate the flood-prone area for the whole basin using historical-hydrogeomorphological reconstitution whilst hydrological-hydraulic modelling in areas with a more accurate database supports the 100-yr estimated return period. The application of both methods has generated new cartographic outputs: whereas identification of critical runoff points is obtained by historical-hydrogeomorphological reconstitution, the depth of the submerged area is obtained by hydrological-hydraulic modelling. These different cartographic outputs must be considered together when delineating the flood-prone areas, as complementary data collection allows for better management of the flooded areas by emphasising the data that controls the processes as well as the exposed elements. The complementary use of different methods to evaluate flood-prone areas needs to be used more extensively.

As final remarks, the use of these two methods to estimate the flood-prone areas highlighted their complementarities and the best performance for each method. In the specific studied area, certain innovative cartographic results made it possible to clearly upgrade the previous definition of the inundated areas. The study also indicated the tangibility of the results for other basin contexts by promoting the best approach for areas with insufficient or missing data, leading to improvements in flood management.

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Hydraulic modelling of the flood prone area in a basin with a historical report of urban inundation: The Arunca River case (Central Portugal)

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ABSTRACT: Floods, considered major hazardous processes due to the rising number of events with high socio-economic impacts causing widespread disturbance, are frequent in the Arunca River drainage basin (Central Portugal) as a result of climatic, morphological, geological, hydrological and anthropogenic factors. The vulnerability of the area has increased in recent decades, mainly due to the disturbances introduced by man (e.g., channel artificialisation and a reduction in the infiltration capacity of the floodplain and cover in urban areas). This paper describes how the 1-D hydraulic model HEC-RAS, using a higher resolution topographic surface including hydrogeomorphological details and other features influencing hydraulics, was applied to four reaches/sections spanning the upper, middle and lower basin of the Arunca River as well as urban and rural areas, in order to determine the flood prone areas for a return period of 100 years. The HEC-RAS results were then compared with the existing flood prone areas. The analysis made possible a new cartographic representation of the flood prone areas in four sections, which represent the most hazardous areas of the basin due to urban occupation (the large concentration of residential, industrial and commercial areas) and communications infrastructures (national and regional roads and national railway). The comparison of the previous flood prone areas represented in the River Mondego Hydrological Basin Plan maps with the new cartographic representation stresses the great variations in the upstream sections (over 20%), due to more significant anthropogenic changes, in contrast with the downstream sections (under 4%). The results of the water height maps emphasise that in the downstream sections measurements of over 2 meters are dominant; 93 ha of Section D, the section furthest downstream, has a water column height of over 4 meters. An analysis of the elements exposed to flooding reveals a total of 391 residential buildings, essentially located in the two major towns (Pombal and Soure). In the downstream sections, the flooded area affects mainly farmland and its corresponding infrastructures. It is also significant to note that in all the modelled sections it is not possible to cross the floodplain area in the event of flooding. These disruptions would have a serious effect on regional and municipal socio-economic flows and connections. The hydrologic-hydraulic modeling, with new relevant data and a detailed DTM, in association with the incorporation of hydraulic and block structures, and anthropogenic morphological and land use changes, has enabled new flood prone areas to be defined and the water height to be mapped for a 100-year return period. This study can serve as a support element in plan-ning updates, including the Master Plans for the Soure and Pombal municipalities and the Mondego Hydrographical Basin Plan.

1 INTRODUCTION

Floods are considered major hazardous processes, given the rising number of events, the large number of people affected, the associated damage and losses and the growing socio-economic impacts which cause widespread disturbance. This is the perspective adopted by the UNISDR (2009), which emphasises the growing risk, driven by the increased exposure of people and assets.

The relevance of mapping flood prone areas is increasing and it is an essential tool for territorial planning policies as well as for risk management. The European Union (EU) has strengthened its approach to policies for the prevention and reduction of flood risks and vulnerability (EC-DGE 2008). In line with policies being developed for water and land use, the EU has approved a Directive (Parliament and Council Decision 2007/60/EC) establishing a framework for the assessment and management of flood risks, with the aim of reducing the adverse consequences. The EU Flood Directive (op. cit.) outlines the scenarios and elements that should inform the preparation of flood hazard maps and flood risk maps on the scale most appropriate for the areas identified. The development of models for the calculation and expression mapping of inundation areas, as well as the evaluation of flow conditions and their severity, are fundamental to the implementation of prevention, reduction and risk mitigation tools and also the implementation of early warning systems. Barroca et al. (2006) and Luino et al. (2009) have also pointed out the relevance of vulnerability or territorial impact analysis within the context of floodplain and flood management planning, which can make an important contribution towards reducing and controlling land damage, especially in an urban context.

The scale of risk analysis and the complexity of the models applied can be adjusted in order to produce reasonable results, and are more dependent on the available resources and data than on quantitative tailored methods (Apel et al., 2009). Different methods of river flow analysis exist, using one-dimensional (1D), two-dimensional (2D) or three-dimensional (3D) models. Examples of applications of these models show that they are always dependent on data quality, both in terms of flow geometry or dynamics, and all models emphasise the importance of good elevation data accuracy, especially with regard to artificialized areas (e.g., Bates and De Roo 2000; Papperberger et al., 2005; Shieh et al., 2007; Fewtrell et al., 2008; Cook and Merwade 2009).

However, recent studies demonstrate that the application of complex models based on high resolution grids does not necessarily result in improvements to flooding analysis, as would be expected but, on the contrary, requires more complex and expensive parameterisation (Horritt and Bates 2002; Aggett and Wilson 2009). 1D models which are able to adjust to modifications in channel geometry and flow data, and allow for flow distribution segmentation based on geometric, hydraulic and roughness characteristics are frequently cited as adequate hazard modelling approaches.

Simulation of water surface profiles for steady flow conditions has been used by several authors (e.g., Correia et al., 1998; Benito et al., 2003; Casas et al., 2006; Vijay et al., 2007; Cook and Merwade 2009), taking into account channel geometry, floodplain conditions, structural controls, bed roughness and peak discharge conditions, specifically through the application of the one-dimensional model HEC-RAS proposed by the Hydraulic Engineering Center's River Analysis System from the US Army Corps of Engineers (HEC 2002a).

In the study area (the Arunca River drainage basin), there is a historical flood record of the different overall flood risks, and the disturbances in urban areas are of particular relevance. One of the oldest recorded occurrences of flooding appears in the 18th century parish records of Soure, and refers to the death of a man washed away by the river flow. Recently, major floods occurred in 2001 and 2006, the latter event causing a large amount of damage and losses, especially in urban areas.

In the last two decades, certain anthropogenic transformations in the area have resulted in the partial channelisation of the river and riverbed dressing, with the consequent modification of floodplain conditions, and the imposition of structural controls. The changes in hydrodynamic conditions are felt especially in the urban and outer urban areas of the two major towns located in the drainage basin area (Pombal and Soure).

The Arunca River drainage basin is covered by a management plan known as the Hydrographical Basin Plan (PBH) for the Mondego River, which contains flood prone area mapping dating from the 1990s. This data was compared with the flood prone areas defined in this paper, which were obtained through the application of hydrological-hydraulic methods.

In order to obtain a better understanding of flow conditions and define flood prone areas over a 100-year period, the study used a 1D hydraulic model, focussing on flow conditions in urban areas for which new data on a scale of 1/2000 to 1/5000 is available.

In the present study, hydrodynamic simulations for flood scenarios were conducted in four distinct areas of the basin with the aim of: a) defining the flood prone areas for a return period of 100 years in sections where data is available for hydraulic simulation; b) evaluating the effect on the flood prone area of the relevant land use changes and imposed control structures introduced into the area in recent years, modifying hydrodynamic conditions; c) identifying the key elements predictable exposed to flooding in urban areas through hydraulic modelling of the flood prone areas on the basis of more reliable data.

2 STUDY AREA

The study area is located in Central Portugal and corresponds to the Arunca River drainage basin (Figure 1). It is part of the Mondego River drainage basin and lies within the parallels 40º 09' 14" N and 39º 46' 33" N and the meridians 8º 43' 06" W and 8º 28' 18" W. The drainage basin has an area of 550 km^2 and a perimeter of 140 km and its main tributaries, in terms of extent and constancy of flow, are the Anços River and the Valmar Stream on the right-hand bank, and the Cabrunca River on the left-hand bank (Table 1).

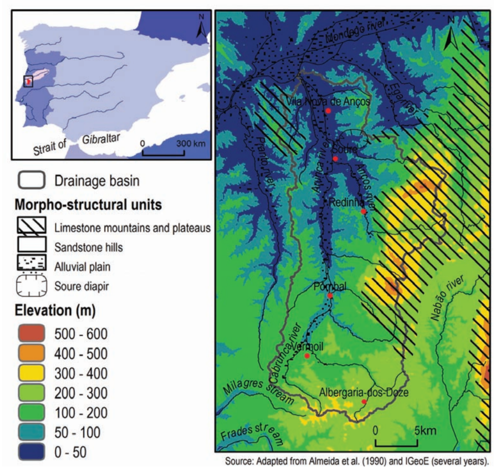

Figure 1. Location and general overview of the drainage basin of the Arunca River (Central Portugal).

Table 1. Physiographical parameters of the Arunca river basin and its main sub-basins.

	Arunca	Anços	Vamar	Cabr.
Area (km^2)	550.1	112.8	49.0	35.3
River length (km)	55.8	15.0	15.7	13.5
Mean altitude (m)	151.0	212.9	182.5	192.4
Mean slope (%)	11.0	13.4	12.4	12.4
Drainage density (km/km^2)	3.4	3.1	3.2	3.8

In geological terms, the basin area includes sedimentary rocks—detritic rocks mainly from the Tertiary and limestones from the Jurassic. In the northern and western areas the outcropping rocks are predominantly detritic, whilst in the eastern area and part of the southern area of the basin limestone predominates.

The altitudes in the Arunca drainage basin range from 553 meters in the eastern area (the geodesic vertex of Sicó) to almost 3 meters at the confluence with the River Mondego (the Arunca River mouth). The basin has a mean slope of about 11% (Table 1), with a maximum value of 125% in the area of the Sicó Calcareous Massif in the eastern part of the basin. The main morphostructural units that can be identified in the basin area are, according to Almeida et al. (1990), the calcareous mountains and plateaus, the sandstones hills, the Soure diapir and the alluvial plain.

From a hydrogeomorphological point of view the basin is contrasted: a) the upstream valley presents moderate hills and a stream incision, b) in the intermediate section, which is the most populated and urbanised area, the valley widens, is asymmetrical in its margins and the main stream begins to drain to the north and c) in the lower course, still framed by asymmetrical margins, the valley is characterised by a wide flat plain extending to the confluence further downstream. The area has a Mediterranean climate with hot summers and mild winters and a high orographical influence on rainfall (oceanic influences are revealed by the rainfall mainly in winter). The mean monthly temperature ranges from 9ºC in January to 21ºC in August and the average annual rainfall is 964.6 mm (figures from the series 1978/79-2005/06).

The mean monthly rainfall data shows the contrast between the eastern area of the basin, with over 1200 mm/year, and the western area, with less than 900 mm/year, mainly between October and January. Almost 20% of the rainfall occurs in spring. The main soil occupations are agricultural, with annual crops and forest land occupying 42.9% and 33.9% of the total basin area, respectively. The areas with a lower infiltration capacity correspond to only 2.5% of the basin area and include urban, industrial/commercial and infrastructure areas. Wet zones, including areas used for growing rice, occupy a very similar area (2.1%).

3 METHODOLOGY / DATA AND METHODS

The 1-D hydraulic model (HEC-RAS—HEC 2002a and 2002b) was applied to four sections of the Arunca River: a) Section A—Ponte de Vermoil/Pinhete; b) Section B—Pombal; c) Section C—Soure and d) Section D—Ponte Mocate/Vila Nova de Anços (Figure 2). These sections were selected with the aim of covering the upper, middle and lower basin of the Arunca River, as well as urban and rural areas, although the choice was strongly influenced by the availability of detailed cartography with data on a scale of 1/10000 to 1/2000.

The application of the hydraulic model was preceded by the calculation, for each of the four sections, of the physiographic parameters, concentration time data and peak flow discharge for the 100-year return period. In generating the model, several sub-basins were considered in each section (Figure 4), contributing towards flow discharge in the modelled area. Section A corresponds to the smallest reach modelled, located in the upper course of Arunca River, and is characterized by physiographic anthropogenic changes associated with a bridge and a landfill construction. In Sections B and C the fluvial stream modelled corresponds mainly to the urban areas of Pombal and Soure, respectively. These two reaches cover the areas with the highest anthropogenic changes

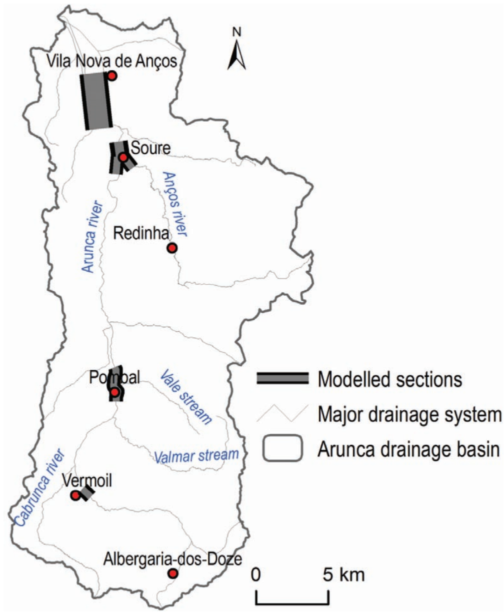

Figure 2. Sub-basins contributing to drainage in the (modelled fluvial sections).

in the channel stream and margins. In Section C, as two main rivers (the Arunca and the Anços—Arunca tributary) converge in the urban area, the modelling was carried out in three separate reaches, two upstream of the confluence and the third after the confluence (Arunca upstream, Anços upstream and Arunca downstream). Finally, Section D corresponds to an area of the Arunca alluvial plain where morphological alterations are less evident and are related to specific changes due to road and railway infrastructures.

3.1 *Data preparation*

The Soil Conservation Service method was applied to estimate the 100-year return period peak flow.

The values for the parameters of the Intensity-Duration-Frequency (IDF) curve used in the calculations are from the Pombal rain gauge station, for precipitation of up to 24 hours for a return period of 100 years, as presented in the Hydrographical Basin Plan (PBH) for the Mondego River (INAG 2000a). The concentration time (Tc) calculated corresponds to the arithmetical mean of the values obtained by the Temez (1978), Chow (1964) and Soil Conservation Service (SCS, 1973) formulae. Tc values range from 4.16 hours in the upstream area (section A) to 10.41 hours in the alluvial plain (section D).

A 1:2000 scale map of the municipality of Pombal (Sections A and B) and a 1:10000 scale map of the municipality of Soure (Sections C and D) were used to define the stream network channel. The original Digital Terrain Model (DTM) needed some corrections in terms of river bed geometry (the stream bed) to improve the morphological representation, particularly with regard to bridges and channel wall geometry. This was achieved through the use of aerial photographs, transversal sections and bridge geometric data obtained from municipal offices, as well field survey measurements.

After the DTM preparation in Triangulated Irregular Network (TIN) format, the ArcGIS extension HEC-GeoRAS version 4.2.92 (HEC 2005) was used to extract the geometric and hydraulic elements required for subsequent hydraulic modelling, including the stream centreline and bank lines (Table 2).

For each of the HEC-GeoRAS layers created it was necessary to associate an attribute table containing information about their positioning along the cross-section. Finally, the geodatabase was exported to Extensible Markup Language (XML) format and subsequently to Spatial Data File (SDF) format so that it was readable in an HEC-RAS environment.

Table 2. Geometric and hydraulic elements for hydraulic modelling.

Flow path centrelines	drawn in the middle of areas with less than 2% slope
Cross-sectional cut lines	placed at regularly spaced intervals except near bridges, where they were set immediately upstream and downstream of the decks at a distance of one metre from the bridge
Ineffective flow areas	inserted immediately upstream and downstream of bridges
Blocked obstructions	placed where large buildings and elevations existed and were not represented in the DTM
Roughness Manning *n* values	extracted from land use interpreted from aerial photographs—the correspondence between classes of land use and *n* values was effected by using the tables published in Matos (1987), Chow (1959) and HEC (2002a, 2002b and 2005)
Levee alignments	placed whenever DTM data could not represent them accurately. However, due to the existing HEC-RAS restriction of entering more than one levee on each side of the channel, whenever possible these levees were represented through the DTM

Table 3. Flow and geometric data of the modelled sections.

	Section A	Section B	Section C			Section D
			Arunca (upstr.)	Anços (upstr.)	Arunca (downstr.)	
100-year flow (m^3/s)	135.9	418.5*	448.1	238.6	686.7	818.8*
Reach length (m)	202.0	2515.0	1078.7	1203.9	883.4	3517.7
Upstream elevation (m)	104.8	61.0	11.09	10.64	9.70	6.95
Downstream elevation (m)	103.6	52.5	9.70	9.70	8.15	3.00
Reach slope (m/m)	0.0059	0.0034	0.0013	0.0008	0.0018	0.0011
Number of cross-sections	30	393	106	166	194	187
Distance between cross-sections (m)	6.7	6.4	10.2	7.3	4.6	18.8
Number of bridges	1	9	0	2	3	2

*value corresponding to the sum of the flow of all contributing tributaries

Table 3 shows the flow and geometric data characteristics calculated for the four fluvial sections. The estimated 100-year flow reveals a huge increase from Section A to Section D due to the important flow contribution of some of the Arunca tributaries, namely the Vale Stream in Section B and the Anços River in Section C.

3.2 *Hydraulic modeling*

The hydraulic modelling considered a steady and unidirectional flow. Computation from one cross-section to the next was based on the solution of the one-dimensional energy equation (HEC 2002b), as follows:

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \qquad (1)$$

where Y_1 and Y_2 are the height of water (m) at cross sections, Z_1 and Z_2 are the elevation of the main channel inverts (m), V_1 and V_2 are average velocities (m/s), α_1 and α_2 are the velocity weighing coefficients, g is the gravitational acceleration and h_e is the energy head loss. The results of this equation are the flow height and velocity in each cross section. The energy head loss estimation is given by the Manning's equation:

$$h_e = L\overline{S_f} + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \qquad (2)$$

where L is the discharge weighted reach length between cross sections (m), S_f is the representative friction slope between two sections (m/m) and C is the expansion or contraction loss coefficient.

The use of HEC-RAS tools can be subdivided into four phases:

– Correcting and adding in geometric data in cross sections and hydraulic structures—after importing the HEC-GeoRAS created layers, some geometric elements had to be corrected or completed, such as the removal of duplicate points in cross sections and the completion of bridge details (piers, side walls, modelling approach, etc.);
– Input of estimated peak flow data for the main channel and its tributaries and definition of the boundary conditions which establish the initial height of water—the normal depth slope was adopted and represents the slope of energy to be used in the Manning's equation (as a simplification, this value was derived from the mean slope of the channel, as accepted and proposed in the HEC-RAS user manual—HEC 2002a). In Section D, observed flow data was available for the Ponte Mocate gauge station (measured heights and corresponding discharges) and was inserted in order to help calibrate the boundary flow conditions.
– General model plan definition—the geometry and flow data files previously prepared were assigned and a mixed flow regime was chosen in order to allow the program itself to select to which cross sections a subcritical or a supercritical flow type should be applied.
– Execution and validation of the hydraulic computations.

3.3 *Validation and comparison of results*

The computed 100-year water surface profiles were exported to a HEC-GeoRAS compatible format. Cross referencing this data with the DTM data in an ArcGIS environment enabled the flood extent and height mapping for the four fluvial sections modelled to be obtained.

As previously mentioned, the flood prone areas mapped using this methodology were afterwards compared with the existing data from the Mondego River PBH.

In some cases, PBH flood maps were produced from existing data on flood prone areas for the 100-year flood period. Where this data did not exist, the PBH adopted a more expeditious method based on the existing drainage network in national mapping on a 1:25000 scale by combining the following polygons, as described in INAG (2000b):

– a buffer of 100 meters around first and second order streams;
– the valley bottom areas with slopes of less than 2% adjacent to second order watercourses and intercepted with alluvial soils.

4 HYDRAULIC MODELLING RESULTS AND DISCUSSION

The results of 1-D model HEC-RAS are presented in Figures 3 to 6 for Sections A to D, respectively,

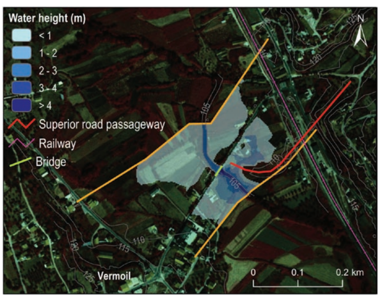

Figure 3. Flood prone area and water heights in Section A.

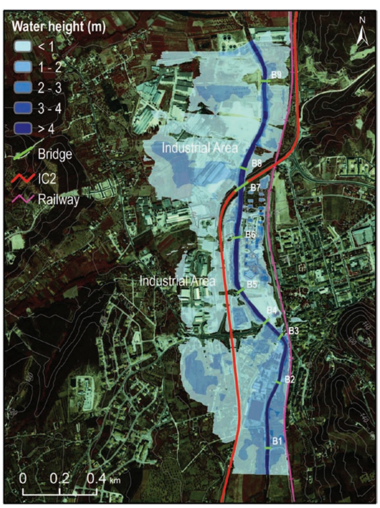

Figure 4. Flood prone area and water heights in Section B.

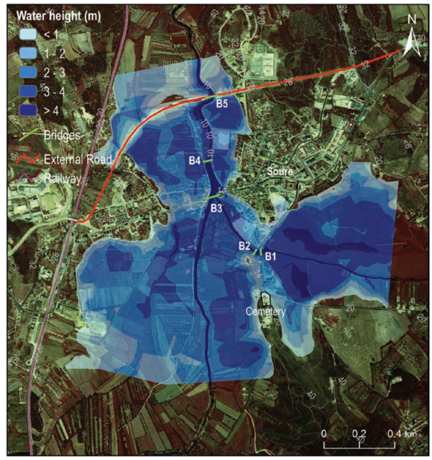

Figure 5. Flood prone area and water heights in Section C.

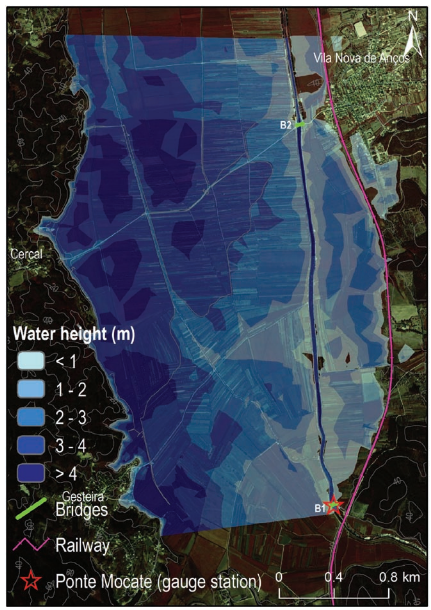

Figure 6. Flood prone area and water heights in Section D.

and in resumed in Table 4 as classified water height values for the flood prone areas in the modelled sections.

From Figure 3 and Table 4 it can be seen that most of the flooded area (79.71%) in Section A presents a water height of less than one metre, whilst the areas with greater heights (>3 metres) correspond to the Arunca channel bed. The road that crosses the floodplain on both sides of the

Table 4. Water height for the flood prone areas in the sections.

	Section A	Section B	Section C	Section D
Total area	4.1 ha	102,8 ha	193,4 ha	706,7 ha
Height	Area (%)			
1 m	79.81	66.51	9.54	9.37
1–2 m	13.14	26.48	17.45	19.30
2–3 m	5.11	1.81	33.58	26.83
3–4 m	1.70	0.95	34.10	31.32
> 4	0.24	4.25	5.33	13.19

Table 5. Exposed elements in the modeled sections.

	Section			
Exposed element	A	B	C	D
Residential buildings	8	208	156	19
Commercial/industrial buildings	1	67	7	3
Social/health/educational facilities	0	3	4	0
Sports and leisure facilities	0	9	3	1
Transport/sanitation/energy structures	0	7	2	0
Bridges	1	4	3	1
Farm buildings	0	2	15	9
Regional and municipal roads	1	2	3	3
Cemetery	0	0	1	1

bridge is clearly an obstacle to the flow, as the flooded area is confined to the channel banks immediately downstream of the bridge. From this figure and Table 5 it can be observed that the exposed elements comprise some residential buildings and the bridge, which is submerged by an 11 cm water column over the bridge deck.

In Section B (Figure 4), the height of the flooded area is mainly lower than one metre. On the eastern side of the area, the railway acts as a longitudinal embankment preventing some urbanised areas from becoming flooded. On the western side, the flood prone area is greater as a result of the larger dimensions of the Arunca river bank; the exposed elements are residential buildings, industrial, commercial and transportation units and sports and leisure facilities (Table 5).

In the central part of the modelled section the existence of embankments prevents flooding in some areas. In this section the highest water column is around 5.5 m, and four of the nine existing bridges may be submerged (with water columns over the bridge deck of 1.32 m, 1.60 m, 0.60 m and 0.75 m for bridges B1, B2, B4 and B8, respectively). The most exposed elements are residential buildings (blocks of flats), industrial plants and public parks, as well as municipal and regional communications infrastructures.

In Section C (Figure 5 and Table 4), it can be seen that most of the flooded area has a water column of over two meters. Almost all of the alluvial plain is flooded, with part of the historic urban area of Soure being exposed. The model also shows that a bridge (B5) obstructs the flow, imposing contrasting water column heights upstream and downstream of its location. In this section, some areas show water heights of over six meters, with the model indicating that three of the five bridges may be submerged (with water columns over the bridge deck of 1.55 m, 1.01 m and 3.10 m for bridges B1, B2 and B4, respectively). As can be seen from Table 5, the exposed elements are essentially residential areas, farmland areas and roads.

In Section D most of the flooded area involves water heights of between three and four meters, corresponding to areas of permanently irrigated land or rice fields (Figure 6). The results of the modelling show that some roads crossing the alluvial plain will be submerged by a water column higher than three meters, the railway embankments serve as conditioning structures and there is an asymmetric distribution of water column heights (the areas with the greatest water height are located on the western side of the river bank, while the lower heights are contiguous to the Arunca river bed). The latter is a consequence of the anthropogenic channelisation of the Arunca River, which previously flowed along the eastern side of the floodplain, and this fact also determines the surge of inundated fields without any overflow at the banks of the River Arunca. Although the most exposed areas are farmland, some urban areas are also exposed, together with some industrial plants. In this section, only one bridge (B2) may be submerged with a 0.36 m water column above the bridge deck.

From the information contained in Figures 3 to 6, and in general terms, the flooded areas increase sharply in an upstream to downstream direction.

Table 5 shows the exposed elements identified in the modelled sections. These results were obtained by fieldwork questionnaires, photointerpretation and city map analysis. Residential buildings are the most affected in all four of the modelled sections. The largest number occurs in Section B (Pombal), totalling 208 buildings including several blocks of flats. The numbers are also high in Section C (Soure), although the residential buildings in question here are mainly detached houses. In Section B, the number of warehouses, commercial and industrial buildings is very large in comparison with the other sections; the higher level of urban occupation explains the presence here of a larger number of sports and leisure facilities which are

Table 6. Comparison of flood prone areas from PBH and the 1-D model (HEC-RAS).

Flood prone area (ha)			
Section	PBH cartography	Modelled cartography	% variation
A	3.0	4.1	+ 36.7
B	129.1	102.8	– 20.4
C	197.4	193.4	– 2.0
D	680.5	706.7	+ 3.9

also affected, as well as transport, sanitation and energy infrastructures.

In Sections C and D, the number of farm buildings exposed to floods becomes more significant as the cultivated floodplain area increases. The most important road affected is the IC 2 (of regional importance), which runs through the town of Pombal. The other roadways affected are also important in the context of each modelled section, but overall are of lesser importance (i.e., are relevant at municipal level only).

4.1 *Comparison with previous mapping of flood prone areas*

Flood prone areas presented in the Mondego PBH, obtained through alluvial cartographic representation, were compared with the 100 year flood limits resulting from the HEC-RAS model (Table 6).

There are some differences between the areas but they are not consistent. A comparison of the previous flood prone areas represented on the PBH (Hydrographical Basin Plan) map with the new cartographic representation emphasizes the variations in the upstream sections, with a considerable amount in Section A (+36.7%) related to changes in land use occupation and the construction of embankments and bridges. In Section B (–20.4%) the area variation is related to topographical changes and river channelisation. In the downstream areas the variations are under 4% due to the width of the floodplain and fewer topographical changes to the margins.

A detailed analysis identifies a greater contribution by river tributaries on the previous maps.

5 CONCLUSIONS

This study has led to a better understanding of the hydrodynamic conditions in the Arunca River basin, thus improving the mapping of flood prone areas.

The hydrologic-hydraulic modelling, supported by new relevant data including a more detailed DTM, in association with the incorporation of hydraulic structures, block structures and anthropogenic morphological and land use changes, has enabled new flood prone areas to be defined and the water height to be mapped for a 100-year return period.

The analysis made it possible to create a new cartographic representation of the flood prone areas in four sections, which represent the most hazardous areas of the basin due to urban occupation (the large concentration of residential, industrial and commercial areas) and communications infrastructures (national and regional roads and national railway).

The comparison of the previous flood prone areas represented in the PBH map with the new cartographic representation stresses the great variations in the upstream sections (over 20%), due to more significant anthropogenic changes, in contrast with the downstream sections (under 4%).

An analysis of the elements exposed to flooding reveals a total of 391 residential buildings, essentially located in the two major towns (Pombal and Soure). It is also significant to note that in all the modelled sections it is not possible to cross the floodplain area in the event of flooding. These disruptions would have a serious effect on regional and municipal socio-economic flows and connections.

This study has made it possible to adopt a more detailed approach to flood prone areas and can serve as a support element in planning updates, including the Master Plans for the Soure and Pombal municipalities and the Mondego Hydrographical Basin Plan.

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The authors wish to express their thanks to the Soure and Pombal Municipalities for the support during the progress of this work (cartographic data) and to the Instituto Nacional da Água and the Administração da Região Hidrográfica do Centro for the information data on Mondego PBH.

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Anexo B2 – Trabalhos de Investigação Originais: Análise do registo histórico de perdas por cheias e inundações

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ORIGINAL PAPER

DISASTER: a GIS database on hydro-geomorphologic disasters in Portugal

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Abstract In the last century, Portugal was affected by several natural disasters of hydro-geomorphologic origin that often caused high levels of destruction. However, data on past events related to floods and landslides were scattered. The DISASTER project aims to bridge the gap on the availability of a consistent and validated hydro-geomorphologic database for Portugal, by creating, disseminating and exploiting a GIS database on disastrous floods and landslides for the period 1865–2010, which is available in http://riskam.ul.pt/disaster/en. Data collection is steered by the concept of disaster used within the DISASTER project. Therefore, any hydro-geomorphologic case is stored in the database if the occurrence led to casualties or injuries, and missing, evacuated or homeless people, independently of the number of people affected. The sources of information are 16 national, regional and local newspapers that implied the analysis of 145,344 individual newspapers. The hydro-geomorphologic occurrences were stored in a database containing two major parts: the characteristics of the hydro-geomorphologic case and the corresponding damages. In this work, the main results of the DISASTER database are presented. A total of 1,621 disastrous floods and 281 disastrous landslides were recorded and registered in the database. These occurrences were responsible for 1,251 dead people. The obtained results do not support the existence of any exponential increase in events in time, thus contrasting with the picture provided to Portugal by the Emergency Events Database. Floods were more frequent during the period 1936–1967 and occurred mostly from November to February.

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Landslides were more frequent in the period 1947–1969 and occurred mostly from December to March.

Keywords Disaster project · Database · Floods · Landslides · Portugal

1 Introduction

In the framework of the United Nations (UN) International Decade for Natural Disaster Reduction (IDNDR 1995), natural disaster was defined as "a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources" (ISDR 2009, p. 9). Therefore, the concept of natural disaster includes the direct and indirect negative impacts to society (in social, economic and environmental terms), resulting from the occurrence of a hazardous natural phenomenon (Alexander 2000; Wisner et al. 2004; NRCNA 2006).

The economic growth and the technological development observed during the twentieth century were not accompanied by the reduction in natural disasters. According to EM-DAT (2013), more than 12,000 natural disasters occurred worldwide in the period 1900–2012, but more than 86 % of events occurred after 1974 (EM-DAT 2013). Moreover, the yearly average number of disasters increased almost 4 times from 1974 to 2012. Within this period, 2.8 million people died and 6.1 billion people were affected by natural disasters (albeit some were affected more than once). In addition, economic, social and environment losses amounted to more than US$ 2.46 trillion (EM-DAT 2013).

The exponential growth of natural disasters in the last decades has been widely discussed by the scientific community. In the case of hydro-meteorological disasters (e.g., droughts, storms, floods), the increasing occurrences may be related to the increasing frequency and magnitude of natural dangerous phenomena, as a direct consequence of climate change (Dore and Etkin 2000; Parry et al. 2007; Gupta et al. 2009). Nevertheless, the increase in disaster number is also noticeable for geophysical disasters (Alcántara-Ayala 2002), and there is no evidence of increment concerning the activity of related natural phenomena (e.g., earthquakes, tsunami and volcanic eruptions).

Therefore, the growth of natural disasters is also related to the uncorrected land use planning, which have been responsible for the increment of risk exposure and people vulnerability, namely in large metropolis and along the coastal zone (Hervás 2003; McInnes 2006).

The inventory, development and exploitation of natural disaster databases have been made worldwide in recent years for different purposes (Tschoegl et al. 2006; Guha-Sapir and Vos 2011). The Global Risk Information Platform (GRIP) provides the access to a world disaster database catalog, facilitating centralized access to disaster loss databases worldwide. The EM-DAT (Tschoegl et al. 2006) is the most important and well-known international database on disasters. Since 1988, the Centre for Research on the Epidemiology of Disasters (CRED) of the University of Louvain maintains the EM-DAT (EM-DAT 2013). This database is compiled from several sources and includes data on natural and technological disasters occurred in the world from the beginning of the twentieth century to the present. At the regional level, the Network for Social Studies on Disaster Prevention in Latin America (La Red 2003) developed in 1994 the DesInventar methodology. This methodology regards the collection of typical disaster standard data (e.g., number of casualties and affected people), but also data on economic and infrastructural damages, as well as data on disaster social effects (La Red 2003). More recently, the DesInventar methodology has been applied in several countries located in Northern Africa, Southeastern Asia and Oceania. At the national level, public services related to civil protection supported the creation of disaster databases in Australia (EMA, Emergency Management Australia), Canada (CDD, Canadian Disaster Database) and the United States (SHELDUS, Spatial Hazard Event and Losses Database for the United States) (Tschoegl et al. 2006).

In Europe, the European Commission empathized the need to have wide monitoring capacities, where the standardization of data collection should be a priority (ECDGE 2008). In this framework, the Spanish Civil Protection promoted the database on floods occurred in Catalonia during the twentieth century to contribute to flood risk assessment and mitigation (Barnolas and Llasat 2007). In Italy, an important effort has been made regarding the production, exploitation and dissemination of disaster information (Guzzetti and Tonelli 2004; Guzzetti et al. 2005; Salvati et al. 2010). Since 1992, a historical database on floods and landslides is maintained under the institutional support of the Italian Civil Protection. The information system on historical landslides and floods in Italy is available online at SICI (http://sici.irpi.cnr.it). A second Web site (http://webmap.irpi.cnr.it/) exploits GIS-based Web technology to display maps of the distribution of sites affected by the historical hydrologic and geomorphologic events in Italy.

The development of natural disaster databases is absolutely decisive for risk management purposes (Devoli et al. 2007) because it highlights the relationships between the occurrence of dangerous natural phenomena and the existence of vulnerable elements (e.g., people, assets and activities) that can be quantified through human and material losses. Recently, risk prevention was assumed to be a priority in Portugal by the National Programme on Politics for Territorial Management (MAOTDR 2006). Furthermore, this general guide for the Portuguese territorial management states that risk management and prevention must be considered in all instruments dealing with territorial planning and management.

Besides earthquakes and volcanic eruptions, hydrologic (floods) and geomorphologic (landslides) events are on the top of natural disasters worldwide as well in the Portuguese territory (Ferreira and Zêzere 1997; Ramos and Reis 2002). Nevertheless, the basic information on past floods and landslides which occurred in Portugal was scattered and incomplete and this is a shortcoming for the implementation of effective disaster mitigation measures.

In 2010, the Portuguese Foundation for Science and Technology funded the project "DISASTER—GIS database on hydro-geomorphologic disasters in Portugal: a tool for environmental management and emergency planning." The DISASTER project aims to create, exploit and disseminate a GIS database on disastrous floods and landslides occurred in the Portugal mainland from 1865 to 2010. Within this subject, the main objectives of this paper are the following:

1. To discuss the concept of hydro-geomorphologic disaster in the Portuguese context;
2. To present the methodological aspects related to hydro-geomorphologic data collection and the construction of a disaster database linked to a GIS;
3. To explore the DISASTER database, including the presentation and discussion of the geographic and temporal distributions of hydro-geomorphologic disasters, the discussion on the completeness of the database, the evaluation of societal risk and the comparison between the DISASTER database and the EM-DAT.

2 Concept of hydro-geomorphologic disaster

Hydro-geomorphologic disasters are natural processes of hydrologic (floods, flash floods) or geomorphologic (various types of landslides) nature that generate adverse consequences as loss of life or injury, property damage, economic disruption or environmental degradation.

Prior to initiate any data collection to build a database on disasters, it is critical to define quantified criteria for the inclusion of any particular event in the database. For example, the entry criteria for NatCat (Munich RE disaster database) are the occurrence of any property damage and/or the existence of any person sincerely affected (injured, dead) (Below et al. 2009). The Insurance Services Office considers a disaster an event that causes $25 million or more in insured property losses and affects a significant number of property–casualty policyholders and insurers (Thywissen 2006). In the case of EM-DAT, for a disaster to be registered, at least one of the following criteria must be fulfilled: (1) 10 or more people reported dead; (2) 100 or more people reported affected; (3) declaration of state of emergency; or (4) call for international assistance.

The EM-DAT criteria are relatively strict if applied at national level, and this may explain the inclusion in this database of only 32 natural disasters occurred in mainland Portugal (Azores and Madeira islands were not considered) during the period 1900–2010 (Fig. 1). In addition, the EM-DAT includes 13 disasters of hydro-geomorphologic origin for the same period (41 % of total natural disasters) (Fig. 1; Table 1). According to the EM-DAT, these hydro-geomorphologic disasters were responsible for 567 death people and 32,966 affected people. Quite surprisingly, the EM-DAT does not report any natural disaster in Portugal for the period 1900–1960. Moreover, for both natural disasters and hydro-geomorphologic disasters, the increase in occurrences with time is apparent, and the distribution of events by decade may be fitted by second-order polynomial trends: $y = 0.1783x^2 - 0.9126x$ ($R^2 = 0.81$) for natural disasters; $y = 0.072x^2 - 0.3666x$ ($R^2 = 0.94$) for hydro-geomorphologic disasters.

Besides the events reported in the EM-DAT to Portugal, many floods and landslides that have resulted in relevant social and economic losses are known to have occurred in the past and should be considered at the national level. Therefore, the entry criteria for the DISASTER project database are the following: any flood or landslide that, independently of the number of affected people, caused casualties, injuries or missing, evacuated or homeless people. We can assume that such consequences are relevant enough to be reported by the press, namely daily newspapers, which are the main source for data collection in the DISASTER project.

In the context of the DISASTER project, the concepts of DISASTER case and DISASTER event need to be clarified. A DISASTER case is a unique hydro-geomorphologic occurrence, which fulfills the DISASTER project database criteria, and is related to a unique space location and a specific period of time (i.e., the place where the flood or landslide harmful consequences occurred in a specific date). A DISASTER event is a set of DISASTER cases sharing the same trigger which can have a widespread spatial extension and a certain magnitude. For example, on November 18, 1983, an intense storm struck the Lisbon area, triggering dozens of floods in this district that were responsible for widespread economic losses, including road and power cuts and led to several casualties (Liberato et al. 2013).

3 The DISASTER project database

The DISASTER project aims to bridge the gap on the availability of a consistent and validated hydro-geomorphologic database for Portugal, by creating, disseminating and exploiting a

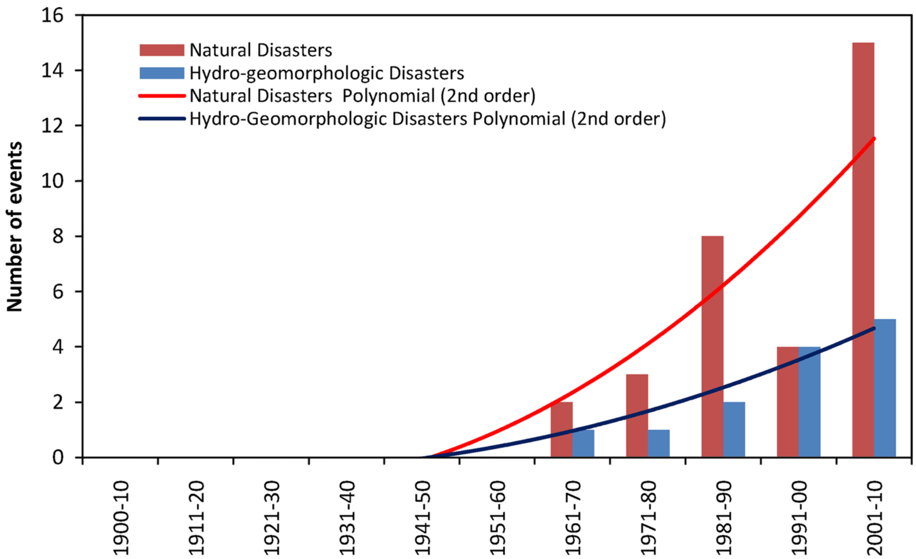


Fig. 1 Natural disasters and hydro-geomorphologic disasters reported for Portugal by the EM-DAT for the period 1900–2010

GIS database on disastrous floods and landslides which occurred in Portugal (Azores and Madeira were not considered) since 1865 (the earliest date for available newspaper records) until 2010.

3.1 Data collection

The methodology used in the DISASTER project for data collection and storage is summarized in Fig. 2. The data collection started with the selection of newspapers to be analyzed by three research teams belonging to the Oporto, Coimbra and Lisbon Universities. Newspapers were selected for systematic survey according to two criteria: (1) The newspaper must have been published continuously for at least 30 years and (2) the set of selected newspapers should guarantee the best regional spatial distribution of the news, in order to cover the entire country.

The set of newspapers that were selected and systematically surveyed for collecting data on disasters is shown in Table 2, which includes the corresponding reference period, category, coverage and spatial incidence. The national daily newspaper *Diário de Notícias* provides the longest time period, having been published continuously since 1865. Two other daily newspapers having a regional coverage were systematically surveyed: the *Jornal de Notícias* published in Oporto (North of Portugal) since 1888 and the *Diário de Coimbra* published in Coimbra (Central Portugal) since 1931. The remaining 8 newspapers are weekly regional and local newspapers published in different regions of the country, thus ensuring the necessary regional coverage. Occasionally, five additional newspapers (*O Século*, *Comércio do Porto*, *O Primeiro de Janeiro*, *Público* and *Correio da Manhã*) were surveyed for some specific dates in order to complete or validate some DISASTER cases (Table 2). In total, 145,344 newspapers specimens were surveyed in order to identify DISASTER cases.

Table 1 Details of hydro-geomorphologic disasters reported for Portugal by the EM-DAT for the period 1900–2010

Disaster code	Start date	End date	District code (see Fig. 12)	Type	No. of deaths	No. of affected people
A	26/11/1967	26/11/1967	12	Flood	462	1,100
B	00/02/1979	00/02/1979	3, 4, 9,11	Flood	4	25,000
C	29/12/1981	29/12/1981	12	Flood	30	900
D	18/11/1983	18/11/1983	12	Flood	19	2,000
E	08/01/1996	08/01/1996	3, 4, 6, 7	Flood	10	1,050
F	22/12/1996	24/12/1996	1, 2, 3, 4, 5	Flood		2,000
G	30/10/1997	08/11/1997	17, 18	Flood	29	200
H	06/12/2000	06/12/2000		Landslide	4	70
I	26/01/2001	29/01/2001	3, 4	Flood	6	200
J	26/12/2002	26/12/2002	1, 3, 4	Flood	1	60
K	01/01/2003	08/01/2003	6, 9	Flood		36
L	22/10/2006	08/11/2006	18	Flood		240
M	18/02/2008	18/02/2008	12, 15	Flood	2	110

Disasters G and H are originally typified as storms in the EM-DAT

District codes: 1—Viana do Castelo; 2—Braga; 3—Porto; 4—Vila Real; 5—Bragança; 6—Aveiro; 7—Viseu; 8—Guarda; 9—Coimbra; 10—Leiria; 11—Castelo Branco; 12—Lisboa; 13—Santarém; 14—Portalegre; 15—Setúbal; 16—Évora; 17—Beja; 18—Faro

Figure 3 shows the temporal coverage of newspapers used for collecting data on hydro-geomorphologic disasters occurred in Portugal. Three distinct periods can be identified according to the number of available newspapers. The first period spans from 1865 until 1907 and is characterized by the existence of up two newspapers (*Diário de Notícias and Jornal de Notícias*) and punctual information gathered from other two newspapers in the end of the period (*Comércio do Porto* and *O Primeiro de Janeiro*). In the subsequent period from 1907 to 1936, four newspapers were available for systematic survey, but only three of them are extended until the twenty-first century (*Diário de Notícias*, *Jornal de Notícias* and *O Algarve: semanário independente*). As for the previous period, punctual data were collected from the *Comércio do Porto* and *O Primeiro de Janeiro*. The 75-year period lasting from 1936 to 2010 is the best covered by newspapers whose number varies between a minimum of nine and a maximum of twelve.

After the selection of titles, the next task was related to the time-consuming reading and interpretation of the news (newspaper analysis) on the newspapers' specimens whose majority were in analogical support (paper or microfilm). During this process, DISASTER cases and events were identified according to the DISASTER project concepts. The complete set of news reporting hydro-geomorphologic DISASTER cases/events was subsequently scanned and converted into digital support (.PDF). Next, all DISASTER cases were validated using the newspaper main report and cross-checking different news sources (national, regional and local newspapers).

3.2 Database structure

The details of characteristics and damages of DISASTER cases were introduced in an online database which was used by the project partners as a client/server model. For maximum

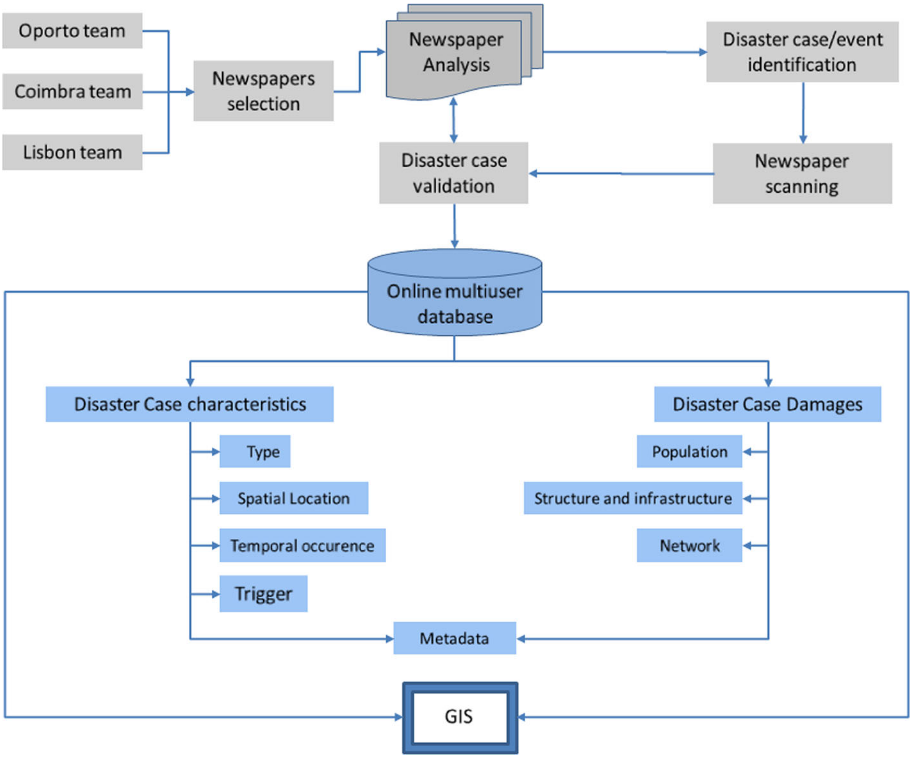


Fig. 2 Methodological scheme for data collection and storage in the DISASTER database

portability, the database was developed on a LAMP platform, comprised of an Apache Web server, a MySQL database engine and using the PHP programming language built on a Linux Server. In addition to portability, this platform also provides an efficient, secure and cost-free solution. The back-office handles all data loading and exporting, as well as future data provision on a public interface.

The multiuser online database comprises two major parts (Fig. 2): (1) the DISASTER case characteristics and (2) the DISASTER case damages. The first part includes data on type (flood or landslide), subtype (flash flood, progressive flooding, urban floods; debris flow; translational slide; rotational slide; earth fall; rock fall; complex slope movement), date (year, month, day and hour), location (council, parish and coordinates of the x and y points according to PT-TM06/ETRS89 projected coordinate system), triggering factor and information source (name, source type and reliability of the news). The size and location of the news of DISASTER cases and events within the newspaper page were also recorded in order to evaluate in a future work the importance given by the media to news on disaster over time.

The complete DISASTER cases were georeferenced using a point shapefile. The precision of location was classified into five classes depending on the quality of the case description in the news: (i) location with exact coordinates (accuracy associated with scale 1:1,000); (ii) location based on local toponymy (accuracy associated with scale 1:10,000); (iii) location based on local geomorphology (accuracy associated with scale 1: 25,000 scale); (iv) location in the centroid of the parish; and (v) location in the centroid of the

Table 2 Newspapers explored for data collection

Newspaper	Reference period	Category	Distribution	Spatial incidence
Systematic survey				
Diário de Notícias	1865–2010	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)
Jornal de Notícias	1888–2010	Daily	Regional	North region (mainly the metropolitan area of Oporto)
Diário de Coimbra	1931–2010	Daily	Regional	Center region (mainly the Coimbra area)
Notícias de Chaves	1950–2010	Weekly	Local	North region (Alto Tâmega)
Correio de Mirandela	1907–1937	Weekly	Local	North region (Trás-os-Montes)
Soberania do Povo	1936–2010	Weekly	Local	Center region (mainly northwest area)
Região de Leiria	1935–2010	Weekly	Regional	Center region (southwest area)
Jornal do Fundão	1946–2010	Weekly	Regional	Center region (mainly east area)
Reconquista	1950–2000	Weekly	Regional	Center region (Castelo Branco and Guarda)
Diário do Alentejo	1933–2002	Daily until 1982 and after then weekly	Regional	South region (Alentejo)
O Algarve: o semanário independente	1908–2001	Weekly	Regional	South region (Algarve)
Punctual survey				
O Século	1934–1968	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)
Comércio do Porto	1899–1926	Daily	Regional	North region (mainly the metropolitan area of Oporto)
O Primeiro de Janeiro	1904–1955	Daily	Regional	North region (mainly the metropolitan area of Oporto)
Público	1996–2010	Daily	National	Portugal (mainly the metropolitan area of Oporto)
Correio da Manhã	2010	Daily	National	Portugal (mainly the metropolitan area of Lisbon and the Tagus valley region)

municipality. Classes (iv) and (v) were considered only when the disaster news did not provide any detailed geographic information.

The second part of the DISASTER database records flood or landslide damages: number of casualties, injuries, missing, evacuated or homeless people, type of damages in buildings (superficial, structural or functional), number of affected buildings, type of damage in networks (superficial, structural or functional), extent of interruptions in road and railroad circulation.

The DISASTER database is linked with a geographic information system in order to facilitate the analysis of both DISASTER cases and DISASTER events.

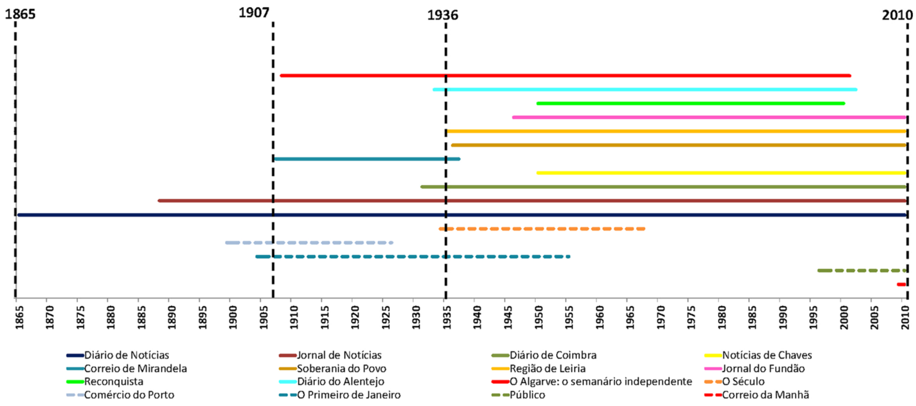


Fig. 3 Temporal coverage of newspapers used in the data collection for the DISASTER database

3.3 Web-GIS design

The DISASTER project Web-GIS server is hosted in the University of Lisbon in the URL riskam.ul.pt/disaster/en and has been implemented with the software GeoServer©, which is an open source software server written in Java that allows users to share and edit geospatial data. This software was designed for interoperability, and it publishes data from any major spatial data source using open standards (http://geoserver.org/display/GEOS/Welcome).

The DISASTER Web-GIS has three main purposes: (1) to make available and free of charge synthesized results from the DISASTER database; (2) to provide location of DISASTER cases (floods and landslides) in Portugal, using the Google Earth© base map; and (3) to provide information about spatial distribution and temporal trends of DISASTER cases and of social damages for hydrographic regions and several administrative units: municipality, district, and NUTS 2 and NUTS 3. The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard developed and regulated by the European Union for referencing the subdivisions of countries for statistical purposes (EC Eurostat 2013).

With the DISASTER Web-GIS, it is possible to make geographic queries, visualize spatial relationships and download data reports with synthesized results (Fig. 4). Geographic queries are made to points of DISASTER floods and landslides. It is also possible to obtain information about location (district, municipality and parish), occurrence date (year, month and day) and precision of location (exact coordinates, based on local toponymy, based on local geomorphology, in the centroid of parish, in the centroid of municipality). It is possible to interactively visualize the location of the DISASTER cases overlapping hydrologic layers (rivers, hydrographic regions), geomorphologic layers (morphostructural units and DTM—50 m pixel resolution) and administrative layers (NUTS 2, NUTS 3, district, municipalities and parishes). However, due to uncertainty regarding the precision of DISASTER cases location, visualization is limited to the maximum scale 1:25,000. In this application, the user has the possibility to zoom in and zoom out the area, select layers to visualize, consult their attributes, do measurements and print the viewing area.

There are 337 profiles available online (in Portuguese) with synthesized disasters data in tables, maps and reports for different administrative units (NUTS 2, NUTS 3, district and municipality) and hydrographic regions. These data reports provide information on the following topics: (1) number of DISASTER cases recorded; (2) spatial location of DISASTER cases; (3) number of fatalities, displaced and homeless people recorded; (4) relative

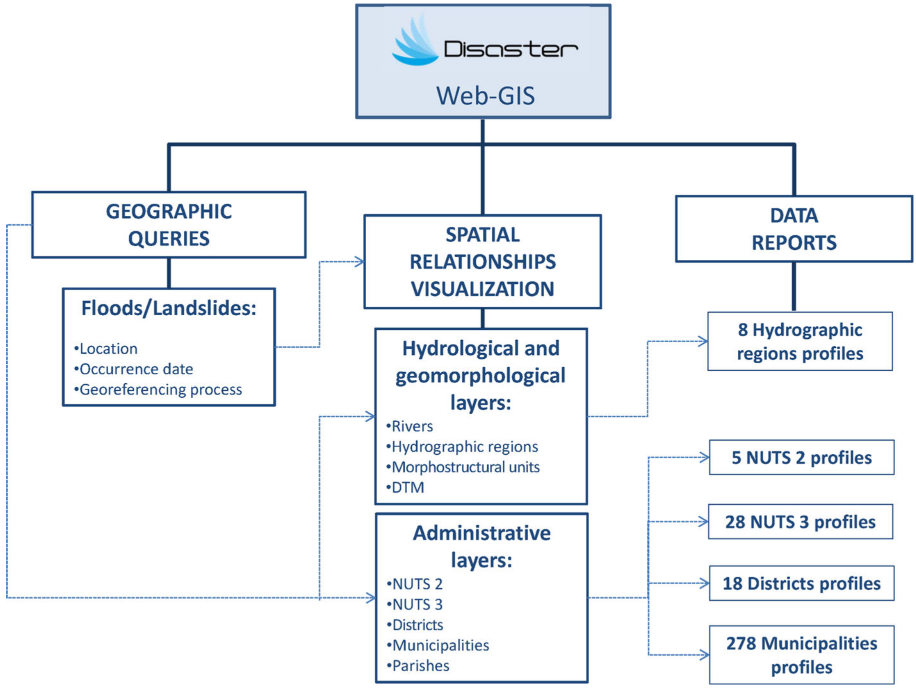


Fig. 4 Disaster project Web-GIS structure

position of the territorial unit in terms of national ranking; and (5) temporal trends of disaster cases and social damages.

4 Database exploitation

The number of cases within the disaster database and their social consequences are summarized in Table 3. In total, 1,902 disaster cases were identified (13 per year, on average) which were responsible for 1,251 deaths (average of 8.6 per year), 14,191 displaced people and 41,844 homeless people. The majority of cases (85.2 %) were floods that generated 81 % of total deaths, 94.2 % of total displaced people and 96.3 % of total homeless people.

4.1 Geographic distribution of hydro-geomorphologic disasters

Disastrous floods occurred in Portugal in the period 1865–2010 were widespread in the country (Fig. 5a, b). Nevertheless, some clusters with high density of flood cases are evident, namely in the Lisbon region and the Tagus valley, in the Oporto region and the Douro valley, in the Coimbra region and the Mondego valley and along the Vouga river valley (Fig. 5a).

Table 4 summarizes the density and impacts of disastrous floods occurred in the eight hydrographic regions of the country. The density of disastrous floods registered in Portugal in the period 1865–2010 is 18.2 per 10^3 km^2. The highest density is observed in the

Table 3 Disaster cases and their social consequences in the period 1865–2010

	Disastrous floods	Disastrous landslides	Hydro-geomorphologic disasters
Number of cases	1,621	281	1,902
Number of deaths	1,012	239	1,251
Number of missing people	71	23	94
Number of injured people	478	422	900
Number of displaced people	13,372	819	14,191
Number of homeless people	40,283	1,561	41,844

Cávado, Ave and Leça region (29.5 cases per 10^3 km^2), which is within the rainiest zone of the country (Fig. 5b). The Tagus region and the Mondego, Vouga, Lis and West river region are in the following positions with 26.3 cases per 10^3 km^2 and 22.3 cases per 10^3 km^2, respectively. The lowest density of disastrous floods is registered in the southern half of the country, including the Guadiana region (3.6 cases per 10^3 km^2) and the Sado and Mira region (5.1 cases per 10^3 km^2). These are dry regions with mean annual precipitation (MAP), typically less than 600 mm (Fig. 5b).

The majority of death and missing people due to floods occurred in the Tagus region (67 % of total). This feature is strongly influenced by a single flash flood event occurred in the Lisbon region in November 25–26, 1967, that generated 522 death people (more than half of total death people due to floods in Portugal in the period 1865–2010). The Tagus hydrographic region registered 59 and 60 % of total homeless and total displaced people, respectively, which results predominantly from frequent flash floods in the Lisbon region (e.g., 1967 and 1983) and general floods in the lower Tagus valley (e.g., 1979 and 1997). The social consequences of floods are also relevant in the Douro region and the Mondego, Vouga, Lis and West river region. The former registered 35.6 % of total homeless people, and the latter registered 14.5 % of total displaced people.

The majority of disastrous landslides that occurred in Portugal in the period 1865–2010 are overwhelmingly constrained in the north of the Tagus valley where the highest hill slopes are to be found (Fig. 6a, b) and where the highest rainfall is registered (Fig. 6d). The majority of landslide cases (91.5 %) are located in areas where the MAP is higher than 600 mm, and 39.5 % of landslides concentrate in area with MAP higher than 1,000 mm.

A large number of landslide cases (39.1 % of total) affected stratified sedimentary and volcanic rocks (Fig. 6c), namely those integrated in the Western Meso-Cenozoic borderland (Fig. 6a). Granites and schists and greywackes belonging to the Hercynian Massif are also within the most landslide-prone lithologic units in the country (34.2 and 17.4 % of total landslide occurrences, respectively) (Fig. 6c).

In Portugal, the average density of disastrous landslides that occurred in the period 1865–2010 is 3.4 per 10^3 km^2. The density of landslide cases is highest in the Lisbon area (including the Lisbon city) and along the Douro valley.

Table 5 summarizes the density and impacts of disastrous landslides occurred within the four morphostructural units that constitute the country. The density of disastrous landslides is the maximum in the Western Meso-Cenozoic borderland (10.3 cases per 10^3 km^2). The remaining morphostructural units have similar landslide density (1.9–2.3 cases per 10^3 km^2).

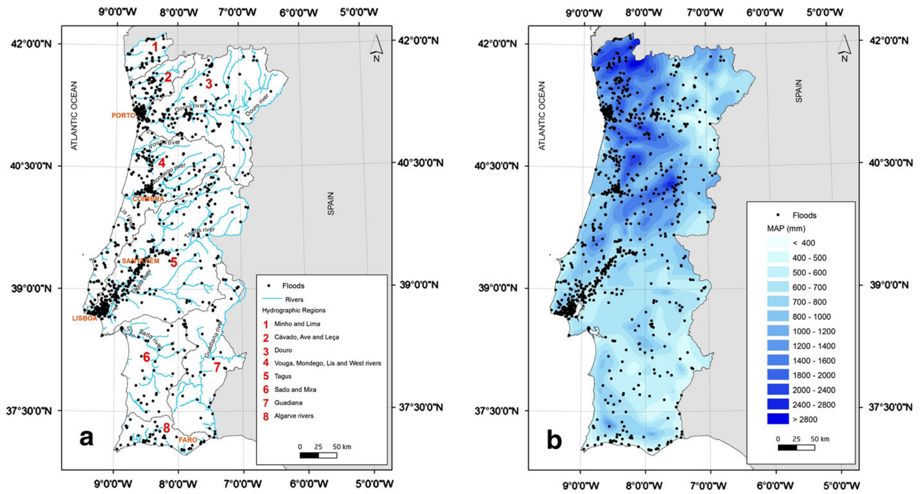


Fig. 5 Spatial distribution of disastrous floods in Portugal in the period 1865–2010 and relationship with hydrography (**a**) and mean annual precipitation (MAP) (**b**). Rainfall data from 1931 to 1960

Table 4 Density and impacts of disastrous floods occurred in the Portuguese hydrographic regions

Hydrographic region	Area (%)	DISASTER cases density (#/10^3 km^2)	Death and missing people (%)	Displaced people (%)	Homeless people (%)
1	2.7	18.7	2.6	1.0	0.0
2	3.8	29.5	3.8	3.6	0.7
3	21.2	18.8	9.5	11.1	35.6
4	15.6	22.3	8.3	14.5	2.7
5	28.2	26.3	67.5	60.0	59.0
6	11.2	5.1	2.8	1.9	0.6
7	13.0	3.6	3.7	0.5	0.4
8	4.3	16.2	1.8	7.4	1.1
Total	100.0	18.2	100.0	100.0	100.0

Hydrographic region codes: see Fig. 5

The majority of death and missing people due to landslides occurred in the Hercynian Massif (72.9 of total), affecting granite and schist, namely in the north part of the country, where disastrous landslides are typically rapid debris flows and rockfalls (Ferreira and Zêzere 1997).

The majority of displaced people due to landslides occurred within the Western Meso-Cenozoic border. In this morphostructural unit, disastrous landslides are typically deep-seated rotational and translational slides. Such landslides have the potential to destroy buildings, but as a rule, they are enough slow moving to allow people to evacuate prior the building collapse.

Homeless people due to landslide activity in Portugal are relevant in the Hercynian Massif (39.7 of total), in the Western Meso-Cenozoic borderland (37 % of total) and in the Tagus-Sado Tertiary sedimentary basin (23.3 % of total). In the latter morphostructural

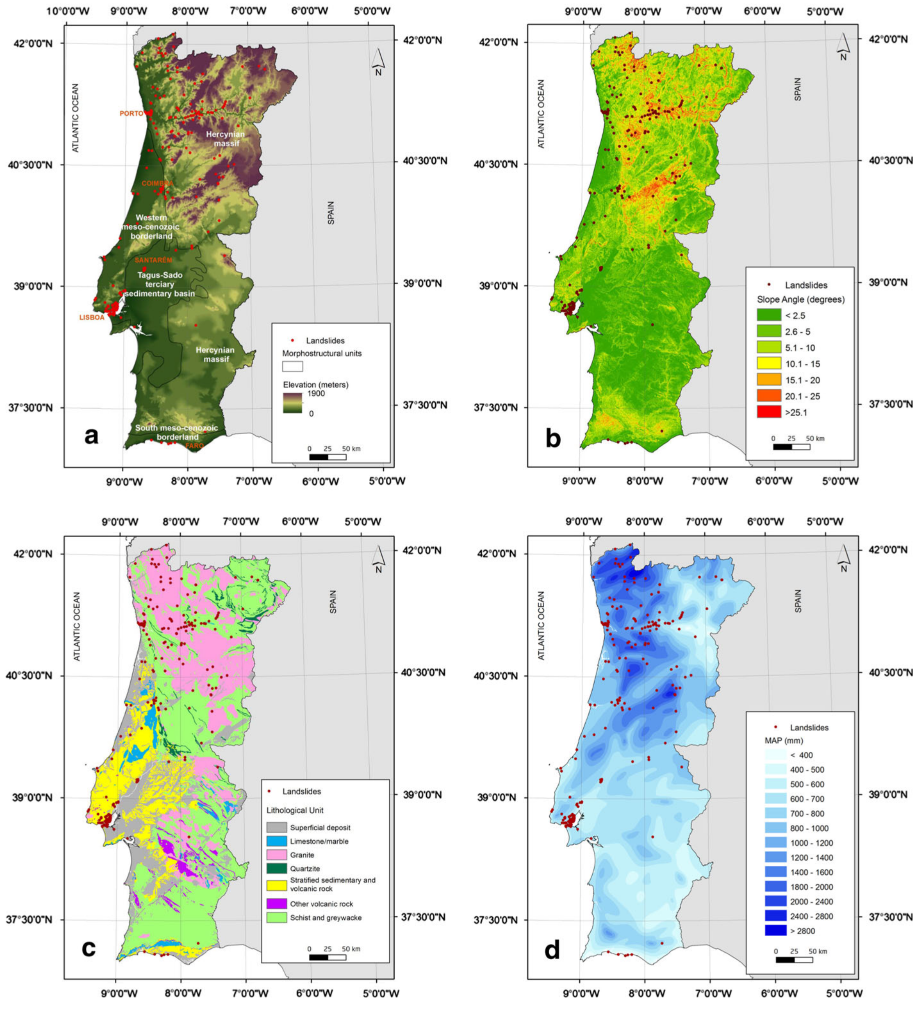


Fig. 6 Spatial distribution of disastrous landslides in Portugal in the period 1865–2010 and relationship with elevation and morphostructure (**a**), slope angle (**b**), lithology (**c**) and MAP (**d**). Rainfall data from 1931 to 1960

unit, disastrous landslides are concentrated in the Santarém region as well as in the south margin of the Tagus estuary.

4.2 Temporal trends of hydro-geomorphologic disasters

The annual distribution of floods and landslides that generated social consequences in Portugal in the period 1865–2010 is shown in Fig. 7. The blue and red lines represent the normalized cumulative disastrous floods and disastrous landslides. The increased slope of these curves is indicative of the increasing number of floods/landslides with time.

It is possible to identify three distinct time periods regarding the temporal trends of hydro-geomorphologic disasters in Portugal: 1865–1934; 1935–1969; and 1969–2010.

Table 5 Density and impacts of disastrous landslides occurred in the Portuguese morphostructural units

Morphostructural unit	Area (%)	DISASTER cases density (#/10^3 km^2)	Death and missing people (%)	Displaced people (%)	Homeless people (%)
Hercynian Massif	84.0	2.3	72.9	21.1	39.7
Western Meso-Cenozoic border	13.1	10.3	21.0	69.2	37.0
South Meso-Cenozoic border	2.9	2.2	2.3	0.0	0.0
Tagus-Sado Tertiary sedimentary basin	17.2	1.9	3.8	9.6	23.3
Total	100.0	3.4	100.0	100.0	100.0

The incidence of disastrous floods and landslides was typically low in the first time period that last 70 years (1865–1934). This time period represents 48 % of the total time series and includes just 20.5 and 17.1 % of disastrous flood and landslide cases registered in Portugal, respectively. The number of flood cases per year was above the annual average (11 cases) in only 7 years (i.e., 10 % of considered years). In the case of landslides, the annual number of occurrences was above the average (2 per year) in just 4 years (5.7 % of considered years). Nevertheless, this first time period includes the year that registered the maximum number of disastrous flood cases in the complete time series (1909: 73 cases). The year of 1909 was marked by an exceptional rainfall period during the second half of December, which generated a disastrous event that spread in the north and central Portugal and was responsible for 34 death people.

The second time period is 35 years long and extends from 1935 to 1969. This time period is the one characterized by the occurrence of the highest number of both disastrous floods and landslides. A total of 781 flood cases (48.2 % of total flood cases) and 133 landslide cases (47.3 % of total landslide cases) were registered during this time period that represents just 24 % of the total time series. For different reasons, 1966 and 1967 were marked by the occurrence of a large number of hydro-geomorphologic disasters (1966: 61 flood cases and 15 landslide cases; 1967: 69 flood cases and 1 landslide case). The hydrologic year 1965–1966 was very rainy in the north and central zones of Portugal where disastrous floods and landslides occurred during more than one month, from January 12 to February 24, 1966. The hydrologic year 1966–1967 was relatively dry, but was marked by a very intense shower in the Lisbon region in November 25-26, 1967, that generated a catastrophic flash flood (Zêzere et al. 2005), which was responsible for the complete flood cases registered in 1967 in the DISASTER database.

The last time period (1970–2010) corresponds to 28 % of the total time series. During this period, 508 flood cases (31.3 % of total flood cases) and 100 landslide cases (35.6 % of total landslide cases) were registered. This time period exhibits an irregular pattern without any clear temporal trend: Years with a large number of disastrous occurrences (e.g., 1979, 1983) are followed by years without any occurrence (e.g., 1980, 1984). The occurrence of high number of disastrous floods and/or disastrous landslides is associated with very wet years: 1978, 1979, 1983, 1989, 1996, 1997, 2000, 2001 and 2006.

Despite the absence of a clear trend, it is impressive that the yearly number of 40 flood cases was exceeded 6 times after 1978, while that feature was reached in just 5 years in the entire previous period (1865–1978). In addition, the number of registered landslide cases exceeds the annual average value in just 13 years within the third time period (31.7 % of

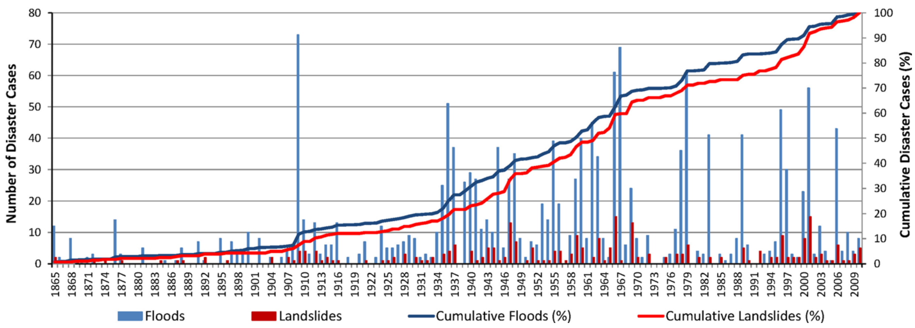


Fig. 7 Temporal distribution of disastrous floods and landslides occurred in Portugal in the period 1865–2010

total). This feature also confirms the irregular character of landslide disaster distribution, which concentrates in some critical years as was the case of 2000 and 2001.

4.3 Seasonal distribution

The seasonal cycle of disastrous floods and landslides occurred in Portugal relative to the entire 146-year period is shown in Fig. 8. Floods are more frequent in months from November to February (75.6 % of total flood cases), while landslides tend to concentrate from December to March (73 % of total landslide cases).

The concentration of landslide occurrences latter on the hydrologic year, when compared with flood occurrences, is consistent with the physical mechanisms involved in both processes, namely in what regards the rainfall-triggering conditions. Flash floods, as well as urban flooding, occur predominantly during the autumn and beginning of winter, usually in response to very intense and short-duration rainfall events (Zêzere et al. 2005; Zêzere and Trigo 2011; Liberato et al. 2013). The timing of landslide occurrence depends on the topography, geology and hydrologic processes in each slope. However, as a rule, landslides having deep failure surface are triggered by the rise of groundwater table, thus requiring the wide, and prolonged in time, water supply to the soil. Therefore, these landslides are typically associated with rainfall periods that may last from several weeks to several months (Zêzere et al. 2005; Zêzere and Trigo 2011) and tend to occur later in the hydrologic year. Such landslide events often occur simultaneously with floods that take place on the large fluvial valleys of the country (e.g., Tagus, Douro, Mondego).

4.4 Completeness of the database

As any other database based on newspaper exploitation, the DISASTER database has biases and is certainly incomplete. However, as Guzzetti (2000) pointed out, it is not straightforward to evaluate the completeness of a historical database on disasters, namely because conditions leading to disastrous floods and landslides (e.g., rainfall regime, land use and people exposition) may have changed over the time period covered by the database. Therefore, the lack of occurrences in a particular time span may result either from variation on conditions that generate floods and landslides (e.g., an anomalous dry period) or from the incompleteness of the database (Guzzetti 2000).

Figure 9 shows the cumulative curves of hydro-geomorphologic cases registered in the DISASTER database for the period 1865–2010. Concerning DISASTER cases, the database may

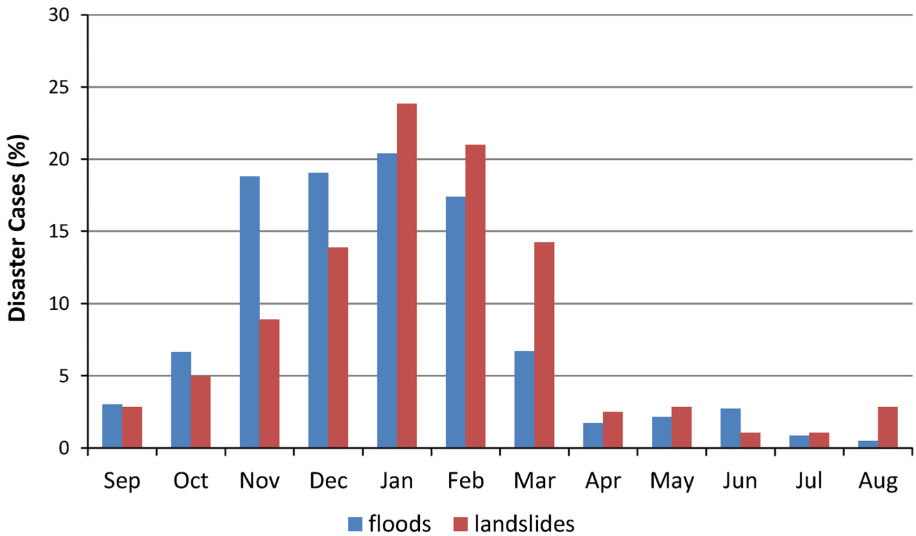


Fig. 8 Monthly distribution of disastrous floods and landslides occurred in Portugal in the period 1865–2010

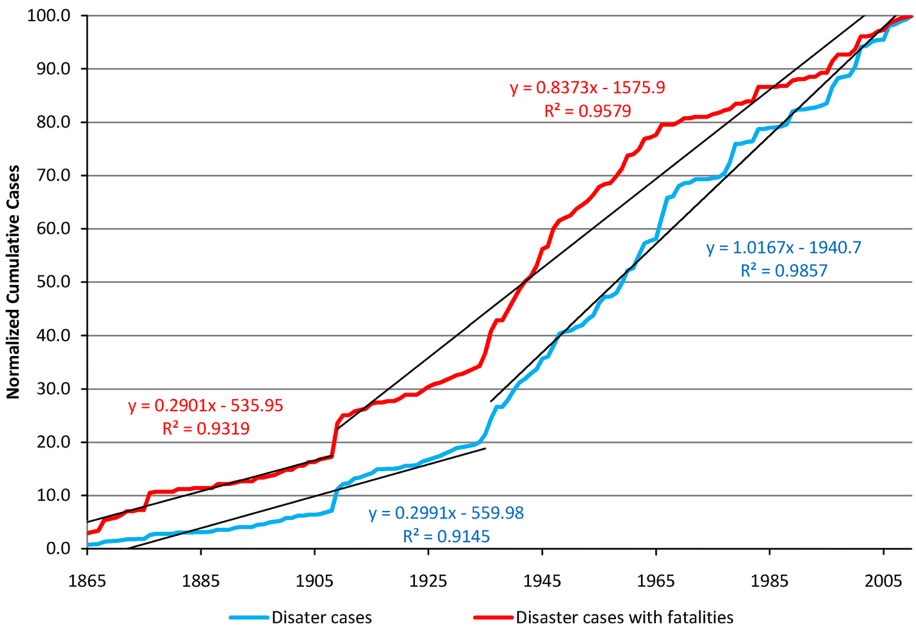


Fig. 9 Cumulative distribution of hydro-geomorphologic disasters occurred in Portugal in the period 1865–2010. The outlier cases of November 25–26, 1967, were not considered

be considered reasonably complete only after 1936, as it is attested by the very regular increase in cases with time since that date ($y = 1.0167x - 1{,}940.7$; $R^2 = 0.99$). In comparison, the first period of time (1865–1936) evidences a lower increase in cases with time

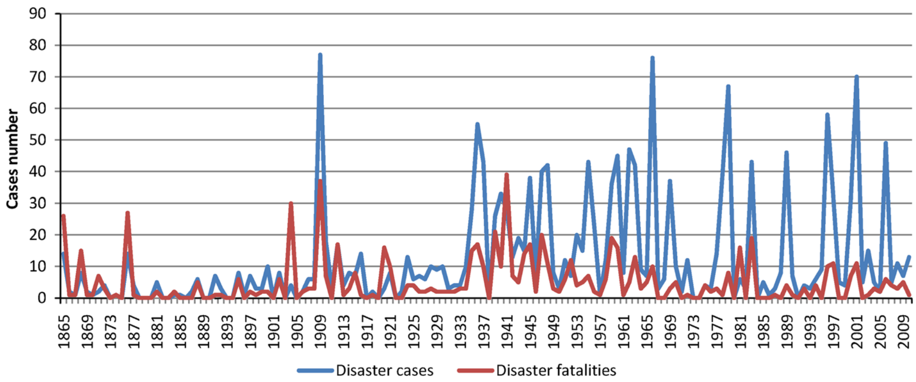


Fig. 10 Annual distribution of disaster cases and disaster fatalities in Portugal in the period 1865–2010. The outlier cases of November 25–26, 1967, were not considered

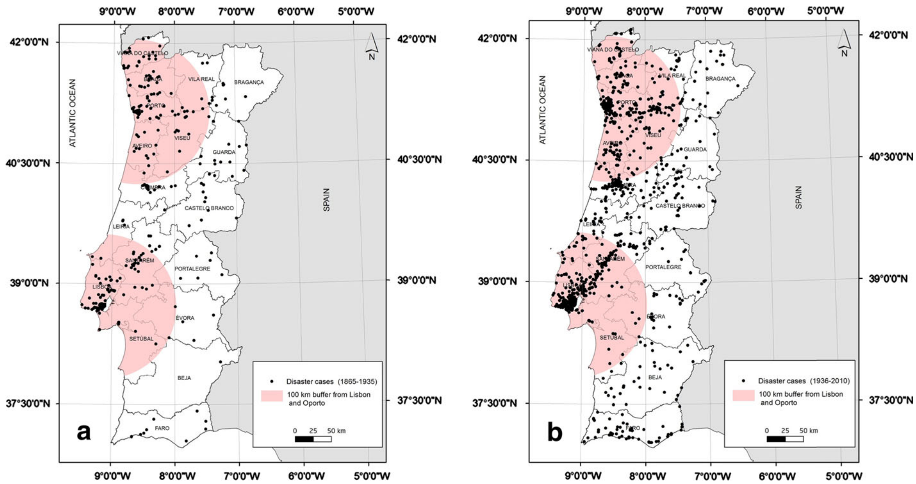
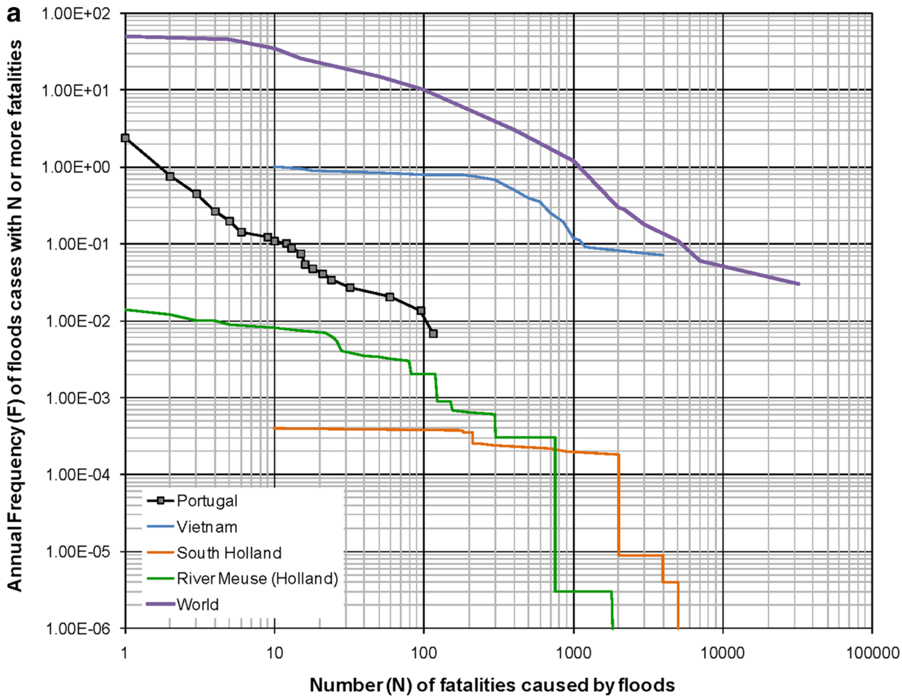
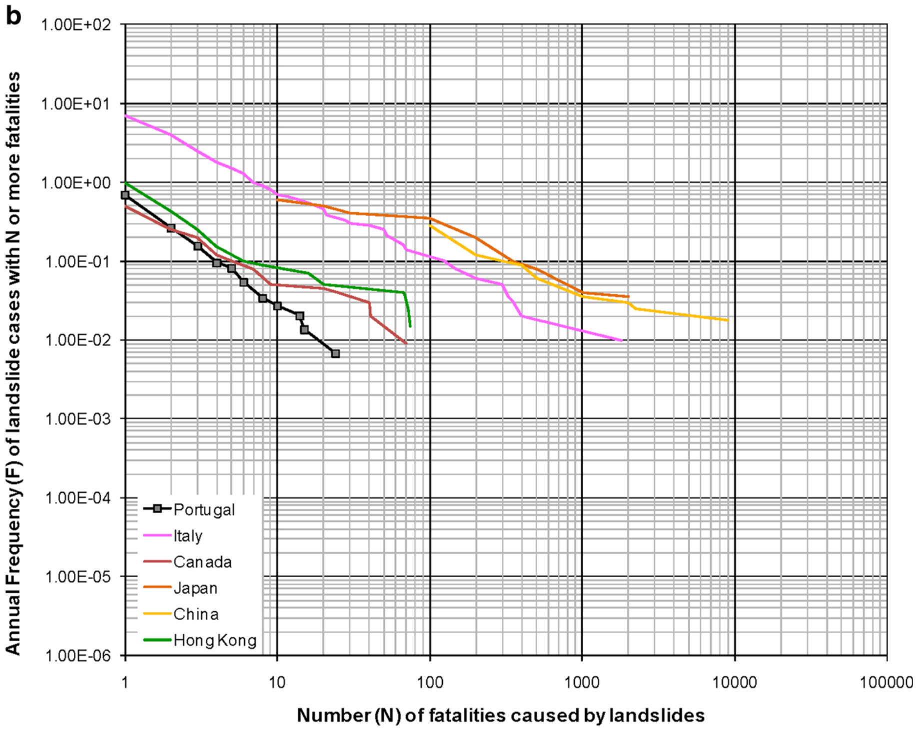


Fig. 11 Spatial distribution of hydro-geomorphologic disaster cases accounting distance from Lisbon and Oporto. **a**—period 1865–1935; **b**—period 1936–2010

($y = 0.2991x - 559.98$; $R2 = 0.91$), which indicates the relative incompleteness of the database. Using the same criteria in the analysis, we admit that DISASTER cases that produced fatalities may be reasonably complete after 1907, which is demonstrated by the regular increase in cases with time since then ($y = 0.8373x - 1{,}575.9$; $R^2 = 0.96$).

The annual distribution of disaster hydro-geomorphologic cases and disaster fatalities is shown in Fig. 10. From this figure, it is evident the incompleteness of disaster cases in the period 1865–1935 in comparison with reported fatalities. Taking into account the relationship established between DISASTER cases and DISASTER fatalities for the complete series and for the period 1936–2010, we estimated that hydro-geomorphologic cases unrecorded in the time period 1865–1935 may amount to 295 cases. This feature represents 42 % of the total DISASTER cases in the time period.


a
Annual Frequency (F) of floods cases with N or more fatalities
Number (N) of fatalities caused by floods
Portugal
Vietnam
South Holland
River Meuse (Holland)
World


b
Annual Frequency (F) of landslide cases with N or more fatalities
Number (N) of fatalities caused by landslides
Portugal
Italy
Canada
Japan
China
Hong Kong

◀ **Fig. 12** Frequency versus consequences (*F–N* plot) for floods (**a**) and landslides (**b**) that caused deaths in Portugal. Similar curves obtained for other countries are presented for comparison. **a** *Floods* World—Jonkman (2005); Vietnam—Mai et al. 2008; South Holland—Maaskant et al. (2009); River Meuse (Holland)—Van Alphen et al., 2011. **b** *Landslides* Italy—Guzzetti (2000); Canada—Evans (1997); Hong Kong—Wong et al. (1997); Japan—Morgan (1997); China—Tianchi (1989), cited in Guzzetti (2000)

The spatial distribution of hydro-geomorphologic disasters for periods 1865–1935 and 1936–2010 is shown in Fig. 11. This figure also shows 100 km distance buffers centered in Lisbon and Oporto. Percentage of cases located 100 km far from Lisbon or Oporto is higher in the period 1936–2010 (32.0 %) than in the period 1865–1935 (28.4 %), which is interpreted as a consequence of a better territorial coverage of newspapers in the latter time period. Therefore, we estimate that an important part (from 35 to 40 %) of unrecorded cases in the time period 1865–1935 should be located more than 100 km far from Lisbon and Oporto, where most newspapers were published.

4.5 The societal risk

The mortality index of both disastrous flood and landslide cases can be computed as the ratio of the number of deaths to the total number of cases for each dangerous phenomenon. The obtained mortality index for Portugal is higher for landslides (0.85) than for floods (0.62). Moreover, the value obtained for floods is strongly influenced by the extreme case (flash flood) occurred in the Lisbon region in November 1967. If we not take into account this event, the mortality index of disastrous floods drops to 0.32. Likewise, while 36.3 % of the landslide cases (102 cases) generated casualties, for flood cases the equivalent feature is just 21.7 %. In addition, this feature falls to 18.3 % when we remove the outstanding event occurred in November 1967.

Despite the apparent tendency for landslides to generate more deaths, the mortality index calculated only for disastrous cases (i.e., those that produced deaths) is higher for floods (2.9) than for landslides (2.3). However, again, the mortality index of floods falls to 1.7 if we not take into account the November 1967 event.

The societal risk is ascertained by calculating the annual frequency of flood and landslide cases that generated fatalities. Figure 12 shows the curves of frequency against consequences for floods (Fig. 12a) and landslides (Fig. 12b) that have caused deaths in Portugal. For comparison purposes, we show similar curves obtained for other countries and previously published (Guzzetti 2000; Jonkman 2005; Mai et al. 2008; Maaskant et al. 2009; Van Alphen et al. 2011).

The frequency of flood casualties in Portugal is lower than the one obtained for Vietnam, but higher than the one that characterizes Holland. The frequency of landslide casualties in Portugal is similar to those computed for Canada and Hong Kong, for cases below 10 fatalities. In addition, the Portuguese curve for landslides is considerably lower than equivalent data obtained for Italy, Japan and China.

Finally, the probability of cases with fatalities is consistently higher for floods than for landslides in Portugal, independently on the number of considered fatalities, which reflects essentially the large difference observed in the number of flood cases (11.1 cases per year in average) and of landslide cases (1.9 cases per year in average).

When compared with the most commonly used risk acceptable criteria (e.g., Fell et al. 2005), the societal risk in Portugal is unacceptable for floods and landslides.

5 Comparison between the DISASTER database and the EM-DAT

The EM-DAT has been maintained by the CRED, with the sponsorship of the United States Agency for International Development's Office of Foreign Disaster Assistance (Guha-Sapir and Below 2006). The database includes data on the occurrence and effects of over 18,000 natural and technological disasters occurred since 1900. The natural disaster category is divided into 5 subgroups covering 12 disaster types and more than 30 subtypes (EM-DAT 2013).

The EM-DAT database is compiled from various sources, including UN agencies, governmental and non-governmental organizations (e.g., the International Federation of Red Cross and Red Crescent Societies), insurance companies, research institutes and press agencies (Scheuren et al. 2008).

Entry criteria of EM-DAT were previously described in Sect. 2. For each reported disaster, three different levels are considered: (1) the event/disaster level; (2) the country level; and (3) the sources level. EM-DAT has historically entered disasters at the country level, but since 2003, disasters have been entered by event (EM-DAT 2013). This change in methodology generates biases in analysis, although according to EM-DAT (2013), regional, multicountry disasters represent only a small percentage of the total number of disasters that are compiled each year.

According to Scheuren et al. (2008), the entries are validated in order to avoid redundancy, inconsistencies and incompleteness. In the majority of cases, a disaster will only be entered into EM-DAT if at least two sources report the disaster occurrence in terms of people killed or affected (EM-DAT 2013). All data that have been validated by the EM-DAT team are made available to the public every three months. Revisions are made annually at the end of each calendar year.

Results of the DISASTER database cannot be directly compared with data for Portugal within EM-DAT for three reasons: (1) the DISASTER database lists disastrous cases, while the EM-DAT lists disastrous events (see Sect. 2 to detail differences); (2) the criteria to include any particular event in each database are not the same; and (3) the time period covered by the two databases is not coincident.

In order to allow a meaningful comparison between the two databases, the following procedures were applied to the DISASTER database: (1) the disastrous cases were grouped into disastrous events, considering as belonging to the same event those cases, spatially coherent, occurred in the same day or in consecutive days, i.e., disastrous cases associated with the same rainfall-triggering condition; (2) the previous defined DISASTER events were filtered using in alternative the two first entry criteria of the EM-DAT—(a) 10 or more people reported dead and (b) 100 or more people reported affected; and (3) events dating from 1865 to 1899 were ignored. Therefore, the time period in analysis becomes the same.

Table 6 summarizes 58 events extracted from the DISASTER database that fulfill the EM-DAT criteria, which are considerably more (446 % in excess) when compared with the solely 13 hydro-geomorphologic events included in the EM-DAT (see Table 1). Events identified in the DISASTER database were responsible for 865 death people and 53,014 affected people. These features are in excess, respectively, 153 and 161 % when compared with equivalent features within the EM-DAT.

The cross-checking between Tables 1 and 6 allows us to verify that, besides some minor differences regarding spatial location and precise number of death/affected people, nine events within the EM-DAT (69 % of total) are in accordance with the information gathered for the DISASTER database (EM-DAT Disaster codes: A, B, D, E; I, J, K, L, M; Tables 1 and 6).

Table 6 Events extracted from the DISASTER database that fulfill the EM-DAT criteria

DISASTER database events							
Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
1	09/02/1904	10/02/1904	2, 3, 4, 6	F&L	30	50	
2	20/12/1909	28/12/1909	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	F&L	34	955	
3	08/12/1910	08/12/1910	3, 7, 13	F&L	2	213	
4	08/02/1912	08/02/1912	8, 12, 13	F&L	14	21	
5	07/01/1920	07/01/1920	14	Flood	15	15	
6	15/02/1936	25/02/1936	3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 17	F&L	10	292	
7	25/01/1937	28/01/1937	3, 6, 7, 9, 12, 13, 15,	F&L	6	211	
8	20/11/1937	20/11/1937	12, 13	F&L	1	315	
9	15/01/1939	19/01/1939	1, 2, 3, 4, 5, 6, 10	Flood	9	165	
10	02/01/1940	06/01/1940	1, 2, 3, 4, 5, 6, 10, 12, 13, 15, 16	F&L	7	1,088	
11	23/01/1941	27/01/1941	10, 12, 13, 14	Flood	3	422	
12	15/02/1941	15/02/1941	12, 15	Flood	33	138	
13	23/09/1943	23/09/1943	12	Flood	0	110	
14	18/11/1945	18/11/1945	12, 15	Flood	2	705	
15	18/12/1945	22/12/1945	3, 7, 9, 11, 12, 17	Flood	9	481	
16	17/02/1947	24/02/1947	1, 3, 6, 9, 11, 12, 13	F&L	6	257	
17	04/03/1947	08/03/1947	3, 4, 7, 12, 13, 16, 17	F&L	2	118	
18	27/01/1948	29/01/1948	2, 4, 5, 6, 7, 8, 9, 10, 14	F&L	9	401	
19	31/03/1952	31/03/1952	11, 12	F&L	11	67	
20	16/12/1953	18/12/1953	11, 18	Flood	3	164	
21	17/12/1955	19/12/1955	13, 16	Flood	0	2,007	
22	24/03/1956	24/03/1956	3, 4	Flood	0	102	
23	03/05/1959	03/05/1959	3	Landslide	8	85	

Table 6 continued

Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
24	27/5/1959	27/5/1959	7	Landslide	6	10	
25	30/12/1961	03/01/1962	3, 4, 5, 7, 8, 9, 10, 12, 15	Flood	0	3,348	
26	04/02/1962	04/02/1962	8	Flood	0	200	
27	12/11/1963	16/11/1963	3, 4, 7, 8, 9	F&L	4	304	
28	14/01/1966	15/01/1966	12	F&L	0	332	
29	20/01/1966	24/01/1966	3, 4, 6, 9, 12	F&L	3	141	
30	02/12/1966	12/02/1966	2, 3, 4, 12	F&L	1	108	
31	18/02/1966	24/02/1966	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 13, 15	F&L	4	2,087	
32	25/11/1967	26/11/1967	12, 15	Flood	522	2,042	A
33	12/03/1969	18/03/1969	3, 4, 7, 9, 12, 13, 15	F&L	3	822	
34	03/02/1972	03/02/1972	9, 12, 13	Flood	0	235	
35	26/02/1978	04/03/1978	2, 3, 4, 5, 9, 12, 13	F&L	0	4,996	
36	07/02/1979	16/02/1979	3, 4, 9, 11, 12, 13	F&L	8	18,473	B
37	27/12/1981	27/12/1981	2	Landslide	15	29	
38	18/11/1983	19/11/1983	12, 13	F&L	18	3,512	D
39	21/11/1983	21/11/1983	15	Flood	0	141	
40	25/11/1988	26/11/1988	18	Flood	0	417	
41	17/12/1989	22/12/1989	1, 2, 3, 4, 6, 10, 11, 13, 14, 15	F&L	1	2,116	
42	26/12/1989	26/12/1989	11, 13	Flood	0	187	
43	12/04/1990	12/04/1990	18	Flood	0	732	
44	29/12/1995	29/12/1995	12	Landslide	0	200	
45	06/01/1996	15/01/1996	3, 4, 6, 7, 12, 13	F&L	6	984	E
46	05/11/1997	06/11/1997	13, 17, 18,	Flood	11	296	G

Disaster database events

Table 6 continued

Disaster database events							
Disaster code	Start	End	District code	Type	No. of deaths	No. of affected people	EM-DAT code (see Table 1)
47	05/03/2000	05/03/2000	12	Flood	0	139	
48	05/12/2000	08/12/2000	1, 2, 3, 4, 9, 10, 11, 13, 16	F&L	5	329	H
49	25/12/2000	27/12/2000	3, 9, 16, 17	F&L	1	150	
50	05/01/2001	07/01/2001	1, 3, 4, 6, 9, 13	F&L	1	122	
51	26/01/2001	27/01/2001	2, 3, 4, 6, 7, 8, 9, 10	F&L	6	983	I
52	06/02/2001	08/02/2001	3, 4, 5, 9, 10, 12, 15	F&L	0	114	
53	26/12/2002	27/12/2002	1, 3, 4	Flood	0	99	J
54	02/01/2003	03/01/2003	6, 7, 9	F&L	0	118	K
55	24/10/2006	26/10/2006	8, 9, 10, 11, 12, 13, 15	F&L	3	367	L
56	03/11/2006	06/11/2006	10, 13, 14, 15, 17, 18	F&L	0	199	
57	18/02/2008	18/02/2008	12, 15	Flood	3	90	M
58	22/12/2009	23/12/2009	3	Flood	0	195	

F&L flood and landslide

Two other events (Disaster codes G and H in Table 1) were misclassified by the EM-DAT regarding the disaster type, as both were originally classified as storm disasters. The event G (Disaster code 46 in Table 6) was characterized by the occurrence of a set of flash floods and floods triggered by a storm progressing from SW to NE that affected the southern part of the country (Faro, Beja and Santarém districts) on the November 5-6, 1997, and intensifying on the other side of the border (Lorente et al. 2008). The number of registered deaths in the DISASTER database is lower than that referred by the EM-DAT (11 against 29), and we admit that the latter may include people dead by floods in the Badajoz province, nearby the Portuguese border, but in Spanish territory where the official counting by the Spanish authorities reported 21 casualties (Lorente et al. 2008). Date and consequences of event H in the EM-DAT (Table 1) are coincident to a landslide case included in the DISASTER database. In December 6-7, 2000, a debris flow occurred in Frades (Viana do Castelo district), generating 4 death people and 12 displaced people. In addition, this landslide case is part of a flood and landslide event (Disaster code 48 in Table 6) occurred in the period December 5-8, 2000, that spread in the north and central Portugal and generated 5 death people and 329 affected people.

The main errors within the EM-DAT database are to be found in Disaster codes C and F in Table 1. According to EM-DAT, a flood caused 30 death people and 900 affected people in the Lisbon region on December 29, 1981 (Disaster code C). Despite the high rainfall registered in Lisbon in the second half of December 1981 (238 mm from December 17–31), there is no notice of any flood generating any death/injured/displaced/homeless people in Portugal during this period. On the other hand, the DISASTER database notices a debris flow occurrence in Cavez (Braga district) on December 27, 1981, that was responsible for 15 deaths and 14 injured people (Disaster code 37 in Table 6). We acknowledge that this disastrous case might be included in the EM-DAT event assigned to the December 29, 1981 (Disaster code C in Table 1). Nevertheless, this single case is not enough to justify the total number of dead and affected people reported by the EM-DAT. That number may also include people affected by severe wind storms that impacted the north and central Portugal during the period December 26–31, 1981. The Disaster code F (Table 1) is, following the EM-DAT, a general flood occurred in the north of Portugal on the December 22–24, 1996, affecting 2,000 people. The DISASTER database does not notice any hydro-geomorphologic case in December 1996 or in January 1997, in any district of the country. In addition, the total monthly amount of rain registered during December 1996 in Lisbon and Oporto (283 and 228 mm, respectively) is not enough to generate a disastrous flood.

The temporal evolution of hydro-geomorphologic disastrous events in Portugal assembled by decade according to the EM-DAT and the DISASTER databases is shown in Fig. 13. As it was previously mentioned in Sect. 2, the EM-DAT database does not report any hydro-geomorphologic disaster in Portugal prior to 1967 and the increase in events with time is apparent. In contrast, the distribution of events belonging to the DISASTER database is far more irregular in time. Twenty-four events included in this database (41.4 % of total events) occurred prior 1960, and the highest values occurred in 1961–1970 and 2001–2010. The distribution of DISASTER database events may be fitted by a logarithmic trend [$y = 2.5555\ln(x) + 1.2067$ ($R^2 = 0.41$)], which is far from any exponential growth tendency.

The MAP computed per decade for Lisbon is also shown in Fig. 13. We acknowledge that the rainfall registered in Lisbon is not illustrative of the triggering conditions of many hydro-geomorphologic events occurred in different zones of the country, but it provides a feasible overview of rainfall variation in time and the relationship with the registered

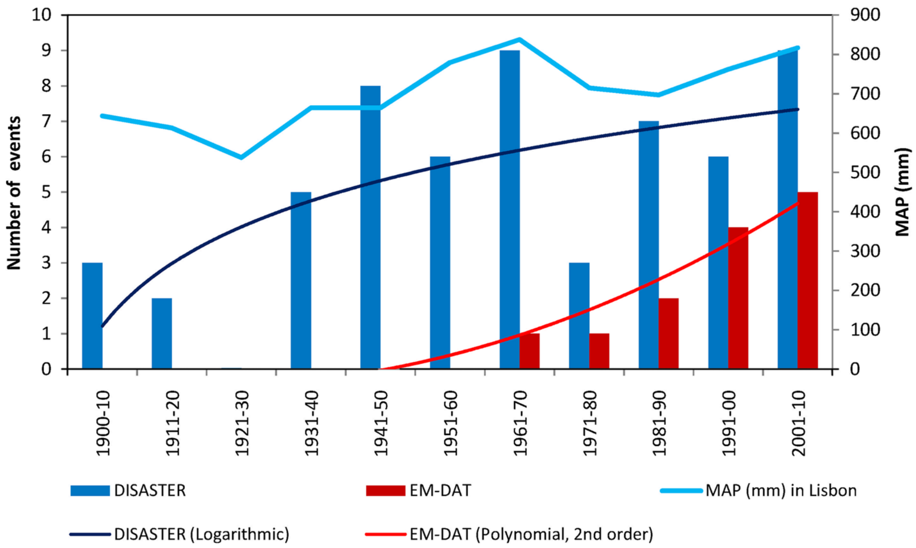


Fig. 13 Temporal evolution of hydro-geomorphologic disastrous events in Portugal according to the EM-DAT and the DISASTER databases. The DISASTER events fulfill the EM-DAT entry criteria

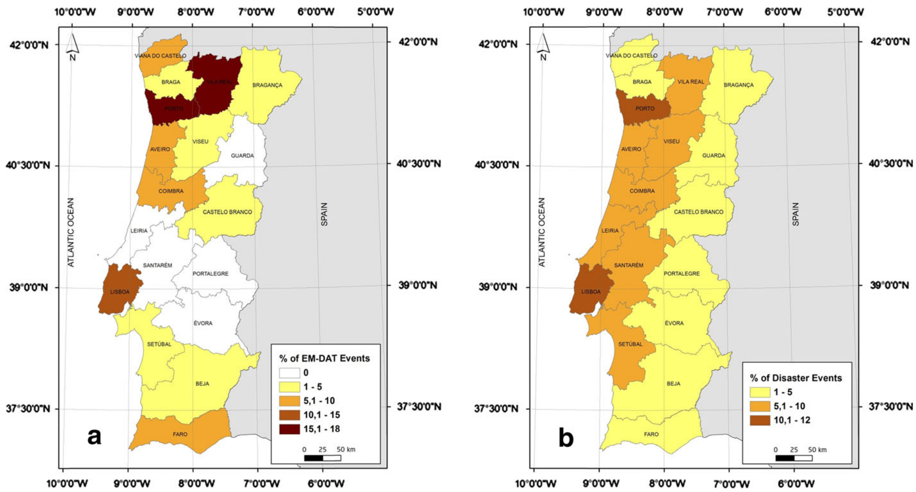


Fig. 14 Distribution of hydro-geomorphologic disastrous events (percentage) in Portugal at the district level according to the EM-DAT (**a**) and the DISASTER (**b**) databases (period 1900–2010). The DISASTER events fulfill the EM-DAT entry criteria

events. In fact, it is noticeable the tendency of DISASTER database events to increase with increasing decennial MAP, which is not the case with the EM-DAT database events.

The spatial distribution of hydro-geomorphologic events reported for Portugal in the EM-DAT (Fig. 14a) is very contrasting when compared with the equivalent map generated with the DISASTER databases (Fig. 14b).

According to the EM-DAT, Oporto, Vila Real and Lisbon are the Portuguese districts with the highest percentage of disastrous floods and landslides. However, reliability of spatial distribution of hydro-geomorphologic events in Fig. 14a is low as there is no logical justification to the absence of events in five districts located in the central–south of Portugal: Guarda, Leiria, Santarém, Portalegre and Évora.

According to the DISASTER database, Lisbon and Oporto are placed on the top rank position concerning percentage of events, followed by Setúbal, Santarém, Leiria, Coimbra, Aveiro, Viseu and Vila Real. These districts are bordering either Lisbon or Oporto and/or are located in the coastal zone. With the exception of the NW districts (Viana do Castelo and Braga) and the Faro district (Algarve), the distribution of hydro-geomorphologic events belonging to the DISASTER database follows the population density within the country (Fig. 15), which is highest in the urban areas along the west coastal zone northward Setúbal and in the south coast of the Algarve.

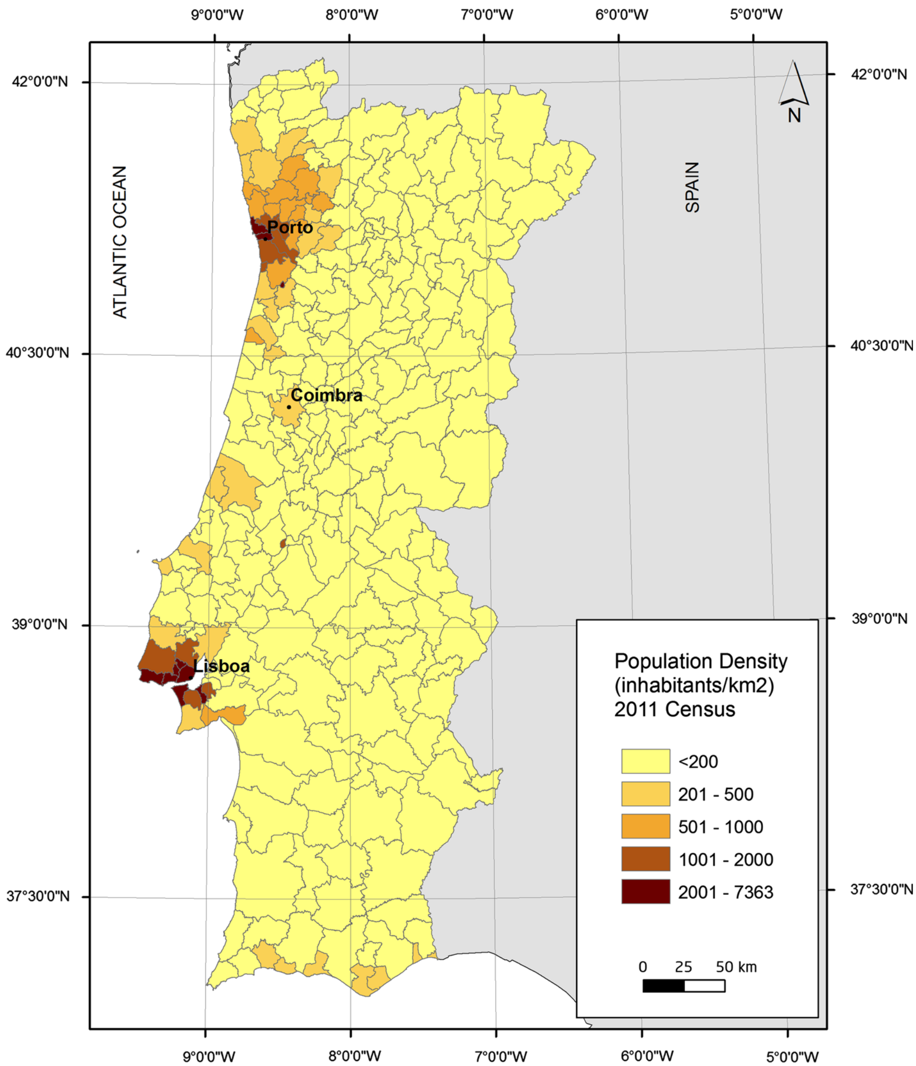


Fig. 15 Population density in Portugal in 2011. *Source of data* Census 2011

6 Concluding remarks

For the first time in Portugal, the DISASTER project created a GIS database on disastrous floods and landslides. The database includes DISASTER cases occurred in the period 1865–2010, which are unique hydro-geomorphologic occurrences related to a particular location and a specific period of time. Any hydro-geomorphologic case was stored in the database if the occurrence led to casualties or injuries, and missing, evacuated or homeless people, independently of the number of people affected. We assumed that such social consequences are relevant enough to be reported by the press, namely daily newspapers, which are the main source for data collection in the DISASTER project.

Data on disastrous floods and landslides were collected from the analysis of 145,344 newspaper pieces belonging to 16 national, regional and local newspapers. However, the temporal coverage of these newspapers is not the same, and the 146-year period under analysis is not uniformly covered regarding the number of existing newspapers. Three time periods were identified regarding the number of existing newspapers: 1865–1907; 1907–1936; and 1936–2010. Two newspapers were available for the first time period, while four newspapers were systematically surveyed for the second time period. The third time period is the best covered by newspapers (from 9 to 12). It is remarkable that the annual number of registered hydro-geomorphologic cases increased significantly since 1935. Besides other reasons (e.g., occurrence of very wet years), this increase might be associated with the higher reliability of sources for the third time period. However, 80 % of total hydro-geomorphologic cases were gathered from only two newspapers (*Diário de Notícias and Jornal de Notícias*) which cover the three time periods.

The DISASTER cases were stored in a multiuser online database which is linked with a geographic information system. In addition, a Web-GIS was implemented that allows making geographic queries, visualizing spatial relationships and downloading data reports with synthesized results.

In total, 1,622 disastrous floods (11.1 per year, on average) and 281 disastrous landslides (1.9 per year) were recorded and registered in the DISASTER database. These occurrences were responsible for 1,251 dead people (8.6 per year), 14,191 displaced people and 41,844 homeless people. Flash floods and floods were responsible for 81 % of total deaths, 94.2 % of total displaced people and 96.3 % of total homeless people. However, the mortality index, obtained as the ratio of number of deaths to number of cases, is higher for landslides (0.85) than for floods (0.62). The tendency for landslides to be more deadly than floods is confirmed by the fraction of landslide cases that produced fatal victims (36.3 % of total landslide cases in the database), which is higher than the correspondent feature for floods (21.7 % of total flood cases in the database).

The density of disastrous floods and disastrous landslides registered in the 146-year studied period is 18.2 and 3.4 per 10^3 km^2, respectively. The maximum density of flood cases is observed in the Lisbon, Oporto and Coimbra regions as well as along the Tagus, Douro, Mondego and Vouga river valleys. The maximum density of landslides occurs in the Lisbon area and along the Douro valley. Although the most affected areas exhibit natural predisposing conditions which favor flood and landslide occurrence, the spatial pattern of hydro-geomorphologic disasters strongly reflects the people exposition which is controlled by the population distribution in Portugal. Indeed, clusters with high density of hydro-geomorphologic cases are located in urban areas within the west coastal zone from Viana do Castelo to Setúbal where the highest density of population is registered.

Three time periods were established regarding the temporal trends of disastrous floods and landslides occurred in Portugal from 1865 to 2010. The first period (1865–1934) was marked by the low number of occurrences: 4.8 floods and 0.7 landslides per year on average, which are fairly below the average for the 146-year period. The second period (1935–1969) is the one with the highest number of hydro-geomorphologic disasters: 22.3 floods and 3.8 landslides per year on average. Floods were more frequent during the period 1936–1967, and landslides were more frequent in the period 1947–1969. Finally, the third period (1969–2010) was marked by the occurrence of 12.4 floods and 2.4 landslides per year, on average, and do not show any evident temporal trend.

We admit the existence of biases in the Disaster database which is certainly incomplete for the period 1865–1935. Sources for this period are limited in number. In addition, importance given to human life and living conditions in that time was less compared to nowadays, namely in the less populated rural areas. Therefore, it is probable that many cases occurred in remote zones in the country have not been reported by newspapers published in Lisbon and Oporto.

The hydro-geomorphologic cases belonging to the disaster database were grouped in disastrous events (i.e., set of disastrous cases associated with the same rainfall-triggering conditions, occurred in the same day or in consecutive days) and constrained to the period 1900–2010 to be compared with the EM-DAT. Accordingly, the Disaster events were filtered using the quantified entry criteria of the EM-DAT: (1) 10 or more people reported dead and (2) 100 or more people reported affected.

The disaster database includes 58 hydro-geomorphologic events that fulfill the EM-DAT criteria which contrast with the 13 events listed by EM-DAT. The incompleteness of EM-DAT regarding disastrous floods and landslides occurred in Portugal is notorious during the complete twentieth century and first decade of twenty-first century but is critical for the period 1900–1966: The EM-DAT does not report any event for this time period, while the disaster database lists 31 events that should be included in the EM-DAT according to the registered social consequences.

The incompleteness of EM-DAT regarding disasters of hydro-geomorphologic origin in Portugal generates an apparent increase in events with time, which is attested by a second-order polynomial trend that fits the distribution of events grouped by decade. The equivalent distribution of disaster database events is fitted by a logarithmic trend, which reflects a more irregular distribution of events in time.

Differences between disaster and EM-DAT databases are also perceptible in the relationship between events and the MAP computed per decade for Lisbon. In fact, it is perceptible the tendency of disaster database events to increase with increasing rainfall, which is not the case with the EM-DAT database events.

Besides the demonstration of non-existence of any exponential growth tendency of the hydro-geomorphologic events, the disaster database also shows a different picture regarding the spatial distribution of disastrous floods and landslides in Portugal. The hydro-geomorphologic events are mostly concentrated in districts located in the west coastal zone from Setúbal to Oporto. Natural conditions are favorable to floods and landslides in these districts, but the high density of events is also related to the high density of population which tends to enhance people exposition to risk.

The spatial distribution of hydro-geomorphologic events belonging to EM-DAT is less reliable. The districts of Oporto and Vila Real are apparently overrepresented, and some important districts are not represented as it is the case of Santarém, Leiria and Guarda.

The disaster project shows the need to create national databases on natural disasters, since the criteria of supranational databases, as the EM-DAT, do not fit detailed scalar context and distinctive organizational reporting. In the particular case of Portugal, the incompleteness of the EM-DAT may originate inadequate conclusions regarding temporal trend and spatial distribution of disastrous floods and landslides.

The national databases on disasters are also important to risk management, namely to prevent, reduce and mitigate disaster risk consequences. These databases should be considered by stakeholders both within the civil protection and the spatial planning, in order to identify critical spots for emergency management and to select safety places for future territorial development. For these purposes, it is decisive to maintain the data collection on disasters after 2010 and this is guaranteed by the RISKam Research Group of the Centre of Geographical Studies, University of Lisbon.

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Risk analysis for local management from hydro-geomorphologic disaster databases

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ABSTRACT

This article describes the applications of a hydro-geomorphologic disaster database allowing a more appropriate local risk management.

Two databases of loss and damage with different criteria, using Central Portugal occurrences, were constructed upon national and regional newspapers: one included all the disaster occurrences regardless of the level of loss and damage reported and the other only the major disasters for which casualties and other human losses were reported.

Risk matrices, exploring likelihood and consequence, were analysed along with data regarding urban and demographic dynamics over time and risk profiles by municipality were obtained.

The results show that the database which only included major disasters produced a risk matrix with lower levels of risk in comparison to the one produced from the more inclusive database.

The most densely urbanised municipalities represent a greater number of disaster occurrences, but when considering only major losses, other peripheral municipalities emerge as high risk. Changes in territorial forcers are shaping the impact patterns in the region. Along with an increase in the housing density, an increase in disasters is observed, although the decrease of inhabitants.

Impacts and territorial forcers cluster analysis and risk matrices' results conduced to municipal risk profiles supporting management. Those profiles conduce to different frames of action from specific emergency planning, warning and alert, multi-hazard planning, or prevention measures involving land use planning or insurance and mutualisation solutions.

Disaster databases that allow differentiating local patterns of impacts–and their respective contexts - contribute to define locally adequate risk management policies.

1. Introduction

The technological development and economic growth that took place during the 20th century was not accompanied by a reduction in the number of natural disasters and their associated damage, leading to a new conceptualization of risk management (Smith and Tombs, 2000). Approximately 9000 natural disasters occurred throughout the world in the period 1900–2003, 80% of which have occurred since 1974

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(Guha-Sapir et al., 2004). In the 21st century, this trend continues. Between 2000 and 2012 the worldwide total damage caused by natural disasters amounted to 1.7 trillion USD, with 2.9 billion people affected and 1.2 million casualties (UNISDR, 2013a). The pressure that is being brought to bear on the planet's resources, with effects on land use and climate change and driven by exponential population growth, is contributing significantly to these figures (UNISDR, 2013b). Nevertheless, if a change in the frequency and magnitude of events is occurring (Field et al., 2012), it cannot be dissociated from changes in exposed elements and vulnerability. Furthermore, not all types of natural disasters may be experiencing the same patterns – for example, normalised flood damage data in the USA for the period 1934–1999 shows a tenuous downward trend (Loucks and Stedinger, 2007), while Europe seems to face the opposite scenario which leads to consider that ''changes in climate cannot be understood as the main reason for increasing flood damage in Europe'' (Barredo, 2007). Finally, disaster databases are susceptible to distinct classifications of the process that caused the damage – storm, flood, hurricane, etc. (Kron et al., 2012).

The importance of adequately registering the historic record of impacts associated with natural disasters is therefore highlighted. Distinct entities and perspectives call upon different data sources, and data collection and organisation still lacks standardisation which can lead to biased and unintended assessment inaccuracies (IFRCRCS, 2005). As a result, an understanding of the databases' level of uncertainty is required (White, 1994; Guha-Sapir and Below, 2002; Smith, 2013). Hydro-geomorphologic related disasters – generally including flooding and slope mass movements – are amongst the more frequent and hazardous disasters worldwide, as can be seen from the several national disaster databases available at the Global Risk Information Platform at www.gripweb.org (GRIP, 2013).

The importance of loss and damage analysis in the risk assessment phase of any flood risk management process has been emphasised elsewhere (Jha et al., 2012; Merz et al., 2011), confirming that the best understanding of impacts is the basis for estimating expected losses from future flood events. Regarding direct physical damage, the authors point out the advantages of using asset databases and stage damage functions.

Several disaster databases exist worldwide, differentiated by the inclusion criteria they adopt. Some of the best known and most widely used are the Emergency Events Database from the Centre of Research on Epidemiology of Disasters (EM-DAT, 2013), the NatCatSERVICE created and managed by Munich RE (Munich Re, 2011) and the DesInventar databases (La Red, 2009). Other national databases referring specifically to flood and slope mass movements related disasters can also be cited, such as the Italian SICI information system containing several disaster databases of which AVI, maintained since 1990, is the most comprehensive (Guzzetti et al., 1994; Guzzetti and Tonelli, 2004), the Spanish Catalonia flood damage database (Barnolas and Llasat, 2007), the Ontario Canadian province floods database (Shrubsole et al., 1993) and the United States flood damage database for the period 1926–2000 from the National Weather Service (Pielke et al., 2002). The scale on which the disaster databases are designed is significant, since estimating the severity of events and their relative level of disturbance in a given area are crucial aspects of risk management (Fischer, 2003).

Several sources can be used to construct a hydro-geomorphologic disaster database: official reports and announcements; data collected during NGO search, rescue and humanitarian operations; data collected as part of research activities by academic institutions, although this often focuses more on the event than its impact; media reports of different types, but especially newspapers (La Red, 2013; Guzzetti et al., 1994; NWS, 2007). The arguments in favour of including newspaper reports as disaster database sources stress the fact that (a) newspapers cover more events and occurrences on a local scale than other sources, (b) the same event and occurrence is frequently reported in different newspapers, thus allowing for comparison and sifting of facts, (c) newspapers are usually better at maintaining and providing access to their archives, (d) newspaper information covers a wider time period than other media sources, such as television and the internet (La Red, 2013).

Loss and damage databases are useful not only in risk management but also in regional and local management in general. The information they provide on severity and probability offers vital support for well-informed disaster risk reduction policies. Risk matrices constructed from probabilistic loss and damage analyses are one of the possible outputs of disaster databases. They offer good potential for territorial differentiation and, despite doubts about their effective contribution towards improving risk information (Cox, 2008), constitute a risk classification tool widely used by risk and emergency practitioners.

The impacts of hazardous events, regardless of their nature, are increasingly forming part of holistic risk governance processes (Dieperink et al., 2013; Tavares and Santos, 2013) which foster consensus and interaction between public and private stakeholders at different power, geographical and decision-making levels (Kasperson et al., 2001). This is even more important given that – apart from the geographical framework – unequal power relations (Collins, 2009) and political ecology (Pelling, 1999) are important factors in the ''hazardscape''. Specifically regarding hydro-geomorphologic risk, attention has focussed recently on the integrated implementation of structural and, in particular, non-structural best practices, ranging from transnational to household level – see Sayers et al. (2013) for flooding, Anderson and Holcombe (2013) for slope mass movements, Holub et al. (2012) and Holub and Fuchs (2009) for hydro-geomorphologic processes in mountain areas.

Embedded in the spirit of the Hyogo Framework for Action, Portuguese policies reflect in planning instruments that emphasise a permanent, multidisciplinary and multisectoral management of risk. The National Programme for the Spatial Planning Policy (Law 58/2007) clearly assumes risk management as one of five backbone vectors in land use policies. This means that the development strategy at any administrative level is obliged to consider risk reduction, prevention and mitigation in the planning process. The downscale implementation occurs through the several Regional Plans for Spatial Planning, from which local strategies for municipal master plans and emergency plans are defined. Funding is a key factor in policy implementation. At the European Union level, such an holistic policy approach is also promoted – framed in the Civil Protection

Financial Instrument for 2014–2020, appealing for ''a more coherent and better-integrated response in the case of emergencies, improved preparedness to deal with disasters and innovative actions to reduce the risk of disaster'' (EC, 2011).

In Portugal, hydro-geomorphologic disasters are amongst the most frequent and severe disasters in terms of the hazardous process as well as the associated losses and damage (EM-DAT, 2013; Ferreira and Zêzere, 1997; Ramos and Reis, 2002; Zêzere et al., 2007). The challenges facing risk management include the reduction and prevention of hazardous processes, reduction of vulnerabilities and risk mitigation, coordination of emergency response operations, improvement of technical/scientific knowledge of risk, and community sensitisation (CCDRC, 2011).

The main objective of this study is to assess the potential and limitations of using hydro-geomorphologic related disaster databases in risk analysis and to support local risk managers. The underlying research questions are framed in three vertical, sequential levels:

- at the level of the disaster database, can it allow for the historical reconstruction of the main hydro-geomorphologic occurrences in the region?
- at the level of the evaluation, does the losses and damages database allows for the application of risk matrix methodologies, and do different criteria influence the hydro-geomorphologic impact analysis?
- at the level of territorial forcers, can the database contribute towards identifying relationships between disasters and the demographic and urban dynamics in the region?

2. Methodology

The general methodology used in the study is described in Fig. 1. In brief, two databases of hydro-geomorphologic disasters occurring during the period 1946–2010 were constructed from printed newspaper sources: one database with

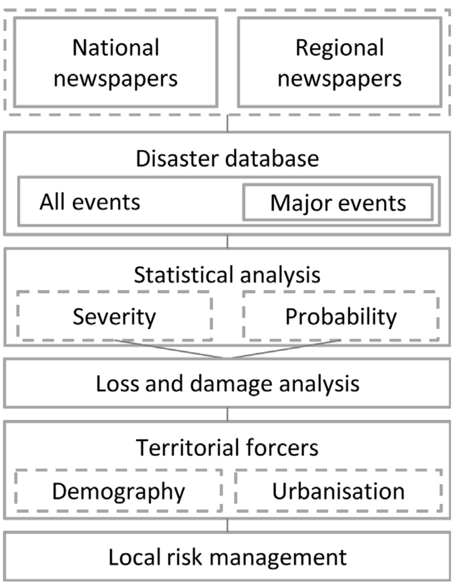

Fig. 1 – Summary of the sequential methodology used in the study.

the major disaster occurrences – following certain criteria with regard to degree of loss – and another with all the disaster occurrences, regardless of the type of loss and damage reported. These two datasets were used to carry out impact analysis based on levels of severity and probability at regional and municipal level, from which risk matrices were produced. Subsequently, the data was crossed-referenced with selected variables expressing territorial forcers, in order to define risk profiles by municipality and provide strategic knowledge to support local risk management tools.

2.1. *Database of losses and damages*

The hydro-geomorphologic disaster databases described here were built as part of a national research project named DISASTER (c.f. Acknowledgements). A national database has been built and maintained since 2009, taking into account the human consequences – deaths, injuries, missing persons, displacement and/or evacuation – reported in the press. Eight newspapers of national and regional distribution were consulted one by one, from 1865 to 2010, and data regarding the characteristics of the hazardous process and of the impacts was extracted and made available via Web-GIS (Zêzere et al., 2014). Before this project, no solid, comprehensive search in the main Portuguese newspapers for reports on this type of disaster had ever been undertaken at national level, although some local and regional inventories already existed. Quaresma and Zêzere (2009) marked the beginning of a change in this situation, compiling an exhaustive database of hydro-geomorphologic disasters for the period 1970–2006 based on newspaper records.

The lack of such data has been acknowledged as a drawback to the implementation of effective disaster mitigation measures and sustainable environmental policies (CCDRC, 2011). Assuming hydro-geomorphologic disasters as tracking marks where the most unfavourable combinations of hazard occurrence, physical exposure and vulnerability are revealed, a loss and damage database was constructed with the aim of understanding where and for whom disaster risk becomes an impact with tangible effects. Other existing databases also consider both floods and slope mass movements in the same disaster category (e.g. Guzzetti et al., 1994; López-Peláez and Pigeon, 2011), justified by the close cause–effect relation with rainfall as the triggering factor. With regard to the chosen study area in Central Portugal – which has homogeneous climatic, hydrologic and geomorphologic features – regional newspapers were consulted as a means of assessing the added value of incorporating regional newspaper information to supplement the data provided by the national newspapers.

2.1.1. *Key concepts*

The hydro-geomorphologic hazardous processes in this database include flooding – except coastal floods – and slope mass movements – slides, flows, spreads, topples and falls – as typified in Varnes (1978). Another important concept is loss (also referred to as human consequences) and damage. In this paper, loss or human consequence represents the direct hazardous effects on humans, including the death, injury, disappearance, displacement or evacuation of one or more people. Damages include the material consequences for any type of facility or property, e.g. road networks, commercial, industrial and residential buildings, educational, health and public administration buildings or farmland.

Concerning database fields, occurrence is defined as the geographically identifiable place affected by flooding and/or slope mass movements where loss and damage are reported. Event is defined as the moment or the continuous time period in which flooding and/or slope mass movements are verified. Three methods for classifying and counting events can be defined (Shrubsole et al., 1993): (1) by the meteorological process that causes the inundations, in which one storm means one event; (2) by the location of occurrences in the watershed: floods occurring in the same watershed belong to the same event; (3) a classification based on the "human settlement", i.e. all floods in the same settlement belong to the same event. In the database used in this study – and given its regional scope – a temporal criterion was used, meaning that occurrences taking place in the same rainstorm are all part of the same event. Slope mass movements may create nuances within this criterion since they can occur within several days, weeks or even months after one or more rainstorms. In this case, an occurrence relating to a mass movement that had occurred in a no-rainfall period was considered a new event, even if it was the result of one or more previous rainstorms.

2.1.2. *Temporal and spatial incidence*

The temporal incidence of the database ranges from 1946 – the year in which the "Jornal do Fundão", the most important regional newspaper published in the study area, was founded – to 2010. The spatial incidence of the database is the inland area of Central Portugal (Fig. 2), an area of approximately 11,880 km^2 consisting of 23 municipalities. Its boundaries in the north and south are defined by the transnational Douro and Tagus rivers respectively, in the east by the Portugal–Spain border and in the west by the Lousã and Estrela mountain ranges.

The figure below also shows the location of the four main economic and demographic municipalities in the area – Castelo Branco, Covilhã, Fundão and Guarda.

The study area is characterised by certain homogeneous characteristics in the context of other natural regions of Portugal (Cunha, 2008). This homogeneity is expressed in terms of rainfall patterns (Cortesi et al., 2013; Daveau, 1998), climate classification – *Csb* climate according to the updated Koeppen–Geiger classification (Peel et al., 2007), geomorphologic configuration (Ferreira, 1980) and human settlements (Daveau, 1998). From the point of view of the planning territorial units, risk prospect and management there's also a similarity of land use and risk patterns in the study area when compared to the rest of the country. Agriculture and pasture still occupies the majority of the soil, followed by increasing areas of forest, and disperse human settlements along permanent and ephemeral streams (CCDRC, 2011). Risk patterns are homogeneous in regard to floods – flash floods prevail over progressive – and slope mass movements which in general present low susceptibility with exception to the flank of the most relevant mountains (CCDRC, 2011).

2.1.3. *Database construction and structure*

This section describes the process followed to build the two used databases. Initially, only national newspapers were used as the source data for disasters. Later – supported by sample cross-checking with regional newspapers and based on individual historical knowledge of past disaster occurrences in the region – the database was supplemented with occurrences reported in regional newspapers, including not only those which had human consequences, but all other

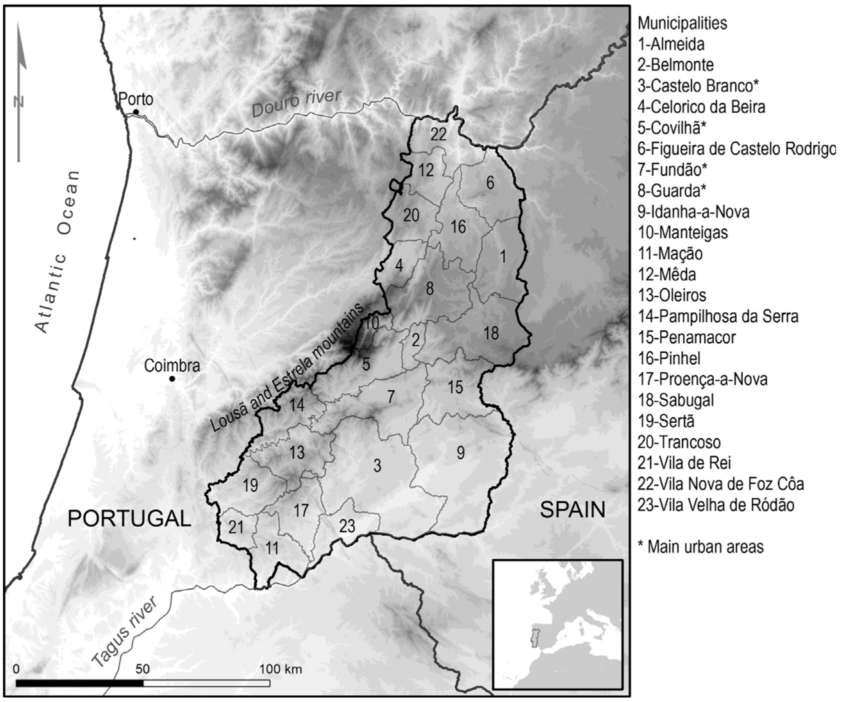

Fig. 2 – Geographical framework for the study area.

Table 1 – List of newspapers consulted as sources for the construction of the databases.

Title	Publication	Coverage	Coverage period
Diário de Notícias	Daily	National	1864–2010
Jornal de Notícias	Daily	National	1888–2010
O Século	Daily	National	1880–1978
Diário de Coimbra	Daily	Regional	1930–2010
Jornal do Fundão	Weekly	Regional	1946–2010
A Reconquista[a]	Weekly	Regional	1945–2010

[a] Consulted in only a few cases for validating and cross-checking local evidence.

occurrences in which property and material damage was reported, regardless of the value of the damages.

A total of approximately 55,000 printed newspaper editions from the period 1946 to 2010 were individually consulted (Table 1).

The database is divided into groups of fields relating to the following: date and place of occurrences and events; source of information and characteristics of the news; direct and indirect associated losses and damages. According to the key concepts indicated, two databases were defined:

- the *Major* database, which only includes occurrences where deaths, disappearances, injuries, evacuations and displacements are reported, independently of their number;
- the *All* database, which includes the *All* database plus all the occurrences where only property and material damages are reported.

2.2. *Loss and damage analysis*

The Standards Australia/Standards New Zealand risk matrix was applied, in which risk is understood as a combination of a disaster consequence (C) and its likelihood (L) (Table 2), according to the criteria defined (AS/NZS, 2005). Likelihood of occurrence was calculated by probabilistic estimation based on the database records for the 64-year period according to Poisson probability distribution and the following classification: 5 – almost certain (more than 1 occurrence every 10 years); 4 – likely (1 occurrence in 10 – 100 years); 3 – possible (1 occurrence in 100 – 1000 years); 2 – unlikely (1 occurrence in 1000 – 10,000 years); 1 – rare (1 occurrence in 10,000 – 100,000 years). The consequences were classified on the basis of the level of loss and damage reported. AS/NZS (2005) defines six types of consequences – profit reduction, health and safety, natural environment, social/cultural heritage, community/government/reputation/media impact and legal consequences. When a newspaper report could be included in more than one of these types, the most severe consequence was considered, according to the following classification: 1 – Insignificant, 2 – Minor, 3 – Moderate, 4 – Major and 5 – Catastrophic.

Table 3 – Statistical data used to analyse territorial forcers.

Variable	Level	Time	Source
Total resident population	Municipality	1950, 1960, 1970, 1981, 1991, 2001, 2011	Census
Total number of houses			

2.3. *Territorial forcers*

In this stage, statistical variables representing socio-economic territorial forcers which were both available for the time period covered by the database and relevant to reconstituting urban and demographic dynamics in the region, were selected (Table 3).

Population and housing densities by square kilometre, broken down to municipal level, were calculated using Census data. This statistical data was analysed by decade, since the Census data refers to 10-year periods, meaning that the average number of occurrences per year in each decade was calculated by grouping the total occurrences registered in the preceding 10-year period. Using the variables that express territorial forcers and the variables that characterise losses and damages, Pearson correlations were calculated and a classification of homogeneous municipalities was produced, based on k-means cluster analysis performed on the same variables. Finally, a risk profile for each municipality was obtained by combining the risk matrix outputs and the analysis of demographic and urban forcers.

3. Results

3.1. *Database statistical analysis*

Table 4 describes and summarises the number of events and occurrences registered in the two databases – the *All* and *Major* occurrence databases – as well as their respective human consequences. In the *All* database, 268 occurrences were reported in the newspapers. Out this total, 48 occurrences comprise the *Major* database. The total number of events is

Table 2 – Risk classification in the AS/NZS risk matrix.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost certain	Medium	High	High	Very high	Very high
Likely	Medium	Medium	High	High	Very high
Possible	Low	Medium	High	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Medium	Medium	High

Table 4 – Occurrences, events and major losses by municipality.

Municipalities	# Major occurr.		# All occurr.		# events[a]			# deaths		# injured		# missing		# displaced		# evacuated	
	F	S	F	S	F	S	Tot	F	S	F	S	F	S	F	S	F	S
1-Almeida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Belmonte	0	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0
3-Castelo Branco	4	1	21	4	10	4	12	1	0	0	1	0	0	16	0	4	0
4-Celorico da Beira	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-Covilhã	9	8	47	27	35	22	53	6	3	2	9	1	0	16	24	2	17
6-Fig. de C. Rodrigo	2	0	4	1	3	1	3	0	0	0	0	0	0	0	0	202	0
7-Fundão	3	0	62	15	27	14	38	1	0	0	0	0	0	0	0	1	0
8-Guarda	3	0	11	4	6	4	8	1	0	0	0	0	0	0	0	6	0
9-Idanha-a-Nova	2	0	3	2	3	2	4	0	0	0	0	0	0	12	0	3	0
10-Manteigas	0	1	1	4	1	3	4	0	0	0	0	0	0	0	4	0	0
11-Mação	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12-Mêda	1	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0	0
13-Oleiros	1	0	5	0	3	0	3	1	0	0	0	0	0	0	0	0	0
14-Pampilhosa da Serra	1	1	5	1	5	1	6	1	0	0	1	0	0	0	0	0	0
15-Penamacor	1	0	18	2	6	2	7	0	0	0	0	0	0	16	0	0	0
16-Pinhel	0	0	7	0	1	0	1	0	0	0	0	0	0	0	0	0	0
17-Proença-a-Nova	0	0	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0
18-Sabugal	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0
19-Sertã	2	0	8	0	2	0	2	1	0	0	0	0	0	0	0	3	0
20-Trancoso	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
21-V.Rei	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0
22-V.N. Foz Côa	1	0	1	0	1	0	1	5	0	0	0	0	0	0	0	0	0
23-V.V. Ródão	4	1	4	2	4	2	6	0	0	4	1	6	0	9	0	30	0
Subtotal	*36*	*12*	*206*	*62*	*114*	*55*	–	*19*	*3*	*6*	*12*	*7*	*0*	*70*	*28*	*251*	*17*
Total	**48**		**268**		**155**			**22**		**18**		**7**		**98**		**×268**	

F – flood, S – slope mass movement.
[a] Total events are not equal to the sum of F and S events because some events include both types of occurrences.

102, which differs from the total of 155 presented in Table 4 since the criteria for identifying events is temporal proximity, meaning that some events affect more than one municipality. Given the total of 102 events, the average number of occurrences per event in the *All* database is 2.63, whereas in the *Major* database the ratio is 1.33.

As can be seen, the majority of events are related to flooding, although in Covilhã (#5) and Manteigas (#10) slope mass movements are also relevant hazardous processes. In general, Table 4 highlights the Castelo Branco (#3), Covilhã (#5), Fundão (#7), Guarda (#8) and Penamacor (#15) municipalities as the most affected. The municipality of Fundão

Table 5 – Probability of experiencing one or more slope mass movement or flood related disasters in the 23 municipalities in the study area: *All* database. Values represent absolute and relative frequency of municipalities.

Probability	1-year		5-year		10-year		25-year		50-year		100-year	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.01	20	87.0	20	87.0	20	87.0	20	87.0	20	87.0	20	87.0
0.1	7	30.4	15	65.2	20	87.0	20	87.0	20	87.0	20	87.0
0.2	5	21.7	14	60.9	15	65.2	20	87.0	20	87.0	20	87.0
0.3	3	13.0	13	56.5	14	60.9	20	87.0	20	87.0	20	87.0
0.4	2	8.7	7	30.4	13	56.5	15	65.2	20	87.0	20	87.0
0.5	2	8.7	5	21.7	13	56.5	15	65.2	20	87.0	20	87.0
0.6	2	8.7	5	21.7	9	39.1	14	60.9	15	65.2	20	87.0
0.7	0	0.0	4	17.4	6	26.1	13	56.5	15	65.2	20	87.0
0.8	0	0.0	3	13.0	5	21.7	13	56.5	14	60.9	15	65.2
0.9	0	0.0	2	8.7	5	21.7	9	39.1	14	60.9	15	65.2
1.0	0	0.0	0	0.0	0	0.0	0	0.0	2	8.7	3	13.0

Note: 13% of the municipalities registered no *All* type occurrences.

Table 6 – Probability of experiencing one or more slope mass movement or flood related disaster in the 23 municipalities in the study area: Major database. Values represent absolute and relative frequency of municipalities.

Probability	1-year		5-year		10-year		25-year		50-year		100-year	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0.01	16	69.6	16	69.6	16	69.6	16	69.6	16	69.6	16	69.6
0.1	1	4.3	9	39.1	16	69.6	16	69.6	16	69.6	16	69.6
0.2	1	4.3	5	21.7	9	39.1	16	69.6	16	69.6	16	69.6
0.3	0	0.0	3	13.0	5	21.7	16	69.6	16	69.6	16	69.6
0.4	0	0.0	1	4.3	3	13.0	9	39.1	16	69.6	16	69.6
0.5	0	0.0	1	4.3	3	13.0	9	39.1	16	69.6	16	69.6
0.6	0	0.0	1	4.3	1	4.3	5	21.7	9	39.1	16	69.6
0.7	0	0.0	1	4.3	1	4.3	3	13.0	9	39.1	16	69.6
0.8	0	0.0	0	0.0	1	4.3	3	13.0	5	21.7	9	39.1
0.9	0	0.0	0	0.0	1	4.3	1	4.3	5	21.7	9	39.1
1.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0

Note: 30.4% of the municipalities registered no *Major* type occurrences.

presents the highest number of *All* type occurrences (74) and the second highest number of events (38) but just 1 death and 1 person evacuated. Pinhel (#16) features only 1 event for which 7 occurrences are registered. In three municipalities there are no occurrences in either database: Almeida (#1), Celorico da Beira (#4) and Mação (#11). The table also shows that some regionally peripheral municipalities such as V.N. Foz Côa (#22) and V.V. Ródão (#23) present a small number of occurrences, although marked with severe consequences as they were responsible for a high number of deaths and disappearances in comparison to the other municipalities.

Applying a methodology similar to Guzzetti and Tonelli (2004) and Coe et al. (2000), the number of municipalities with a given probability of exceedance was calculated for several return periods, according to Poisson probability distribution (Tables 5 and 6).

As can be observed, 3 municipalities (13% of 23) have a 50% probability of experiencing one or more hydro-geomorphologic disasters of the *Major* type within a 10-year period. This number rises to 13 (56.5%) when the *All* database is considered.

Fig. 3 shows the relationship between events and *All* and *Major* type occurrences. In 41 of the 64 hydrologic years no *Major* type occurrences were registered. In the *All* database, an absence of occurrences is verified in 19 hydrologic years. The figure stresses the high inter-annual variability in terms of number of events per hydrologic year and the corresponding occurrences. This is in accordance with the irregular annual rainfall patterns that are characteristic of the Mediterranean and temperate climates studied comprehensively by several authors in the Portuguese context (e.g. Daveau, 1998). The maximum number of both *All* and *Major* type occurrences in one hydrologic year was 41 and 6 respectively, which occurred in 2006–2007, although in terms of human consequences this was not the most severe year, involving one death, one injury and 14 people evacuated. The hydrological years 1962–1963, 1989–1990 and 2001–2002 are marked by a high number of events but a relatively small number of occurrences. Apart from these deviations, in general it can be observed that there is a strong correlation between the number of occurrences and events by hydrological year in both *All* ($R^2 = 0.94$) and *Major* ($R^2 = 0.99$) databases (Fig. 4).

In seasonal terms there is a concentration of *All* type occurrences between October and January. With regard to the *Major* database, the months with higher frequencies extend to

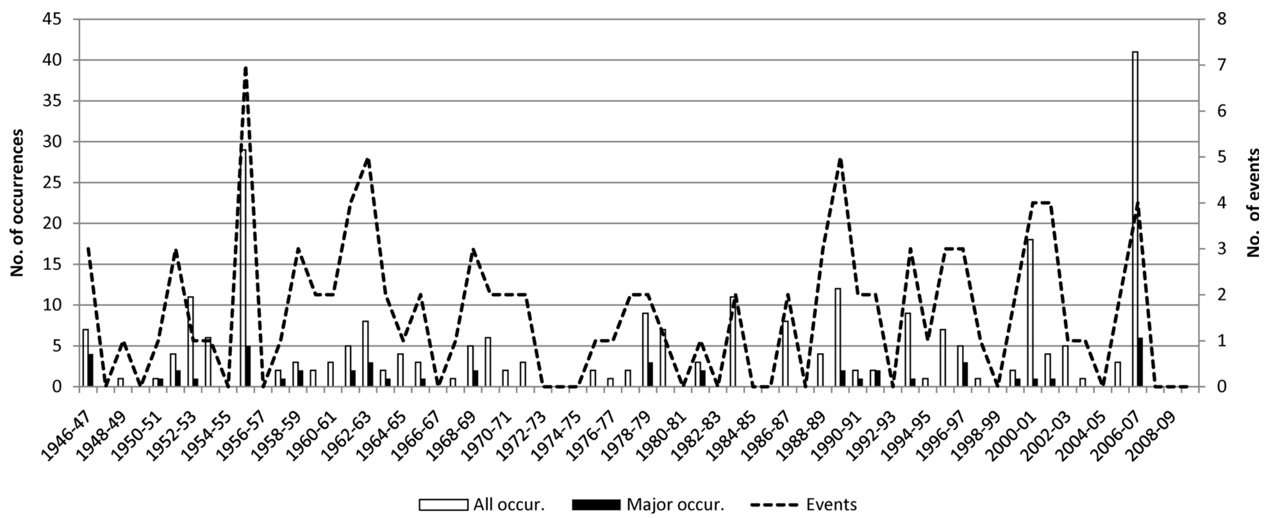

Fig. 3 – Relationship between events and occurrences by hydrological year.

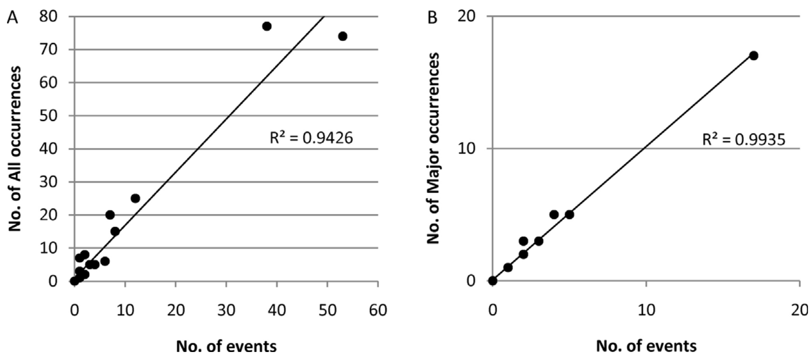

Fig. 4 – Relationship between number of events and occurrences by hydrological year for the *All* database (A) and the *Major* database (B).

March, with the maximum value reached in February (Fig. 5). The monthly distribution of disasters in which deaths and disappearances occurred shows an abnormal value in January, when only 2 events were responsible for 5 deaths and 6 disappearances, in 1963 and 1969, respectively.

3.2. *Risk matrices*

Risk matrices were produced from the two databases (Fig. 6) in which the municipalities were classified by their position in terms of likelihood and consequence. In both risk matrices only values of 4 and 5 were ascribed to likelihood. This is justifiable since the time series totals 64 years and therefore the likelihood of 1 occurrence in 100 and up to 1000 years is never verified. The risk matrix constructed solely from the *Major* database shows a drop in the likelihood category for some municipalities – particularly from the ''very high'' to the ''high'' risk class – and the absence of some municipalities represented in the *All* risk matrix. Meanwhile, the municipalities most severely affected by disasters – i.e. those which experienced deaths and missing persons – maintained their position in both matrices (e.g. Covilhã (#5), V.N. Foz Côa (#22) and V.V. Ródão (#23)). Finally, no municipality changed from one consequence class to another in either risk matrix: only changes in likelihood can be observed.

If the regional newspapers – the Jornal do Fundão, Reconquista and Diário de Coimbra – had not been used, only 17 of the total 48 occurrences in the *Major* database would have been registered, i.e. 31 occurrences with human consequences were not reported in the national newspapers. Conversely, 12 of the 48 *Major* type occurrences, representing 3 casualties (13.6% of the total), 4 injuries, 6 missing people (85.7% of the total), 1 displaced person (1.0% of the total) and 214 evacuated people (79.9% of total), were not reported in the regional newspapers. It may therefore be concluded that both types of press complement each other.[1]

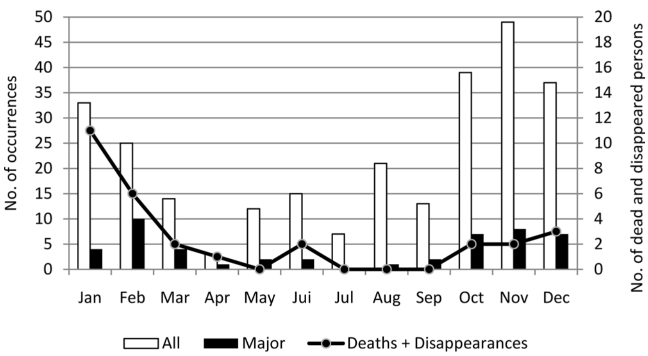

Fig. 5 – Seasonal distribution of *All* and *Major* type occurrences and number of dead and missing persons.

3.3. *Territorial forcers*

In this section, variables that express urban and demographic dynamics are analysed, together with the disaster database records. Fig. 7A reveals a negative correlation of −0.748 between housing and population density in the study area. Whereas the former has increased steadily since 1961–1970, population density has fallen consistently throughout the entire time period in the series.

Several geographical dynamics can be interpreted from both Fig. 7A and B before and after 1970 (see dashed lines). The mean number of occurrences per year increased from this decade onwards, whilst housing density began a period of continuous increase. A reduction in severe human consequences (Fig. 7B) can be observed after 1970, with the exception of the 1991–1992 hydrological year in which there were 3 deaths and 3 cases of missing people.

Fig. 8 facilitates the regional interpretation of disaster data at municipal level. Prior to 1980, only 3 municipalities (#5, #7 and #15) showed *All* type mean occurrences per year of over 0.8. From this decade onwards, 3 other municipalities – Castelo Branco (#3), Guarda (#8) and Sertã (#19) – registered mean occurrences per year of over 0.8, accompanying the increase in housing density. In short, there is a relationship between urban growth and the number of hydro-geomorphologic

[1] A risk matrix constructed only from national newspaper reports would reveal significant differences in the municipal classification of risk, where 13 of the 23 municipalities show absence of *Major* type occurrences: for instance, the Covilhã municipality (#5) drops from the ''very high'' risk to the ''high'' risk class and V.N. Foz Côa (#22) which is classified as a ''very high'' risk municipality does not register any type of occurrences in the national newspapers. This confirms the initial sense that the national newspapers alone were not adequately covering the historical record of hydro-geomorphologic disasters.

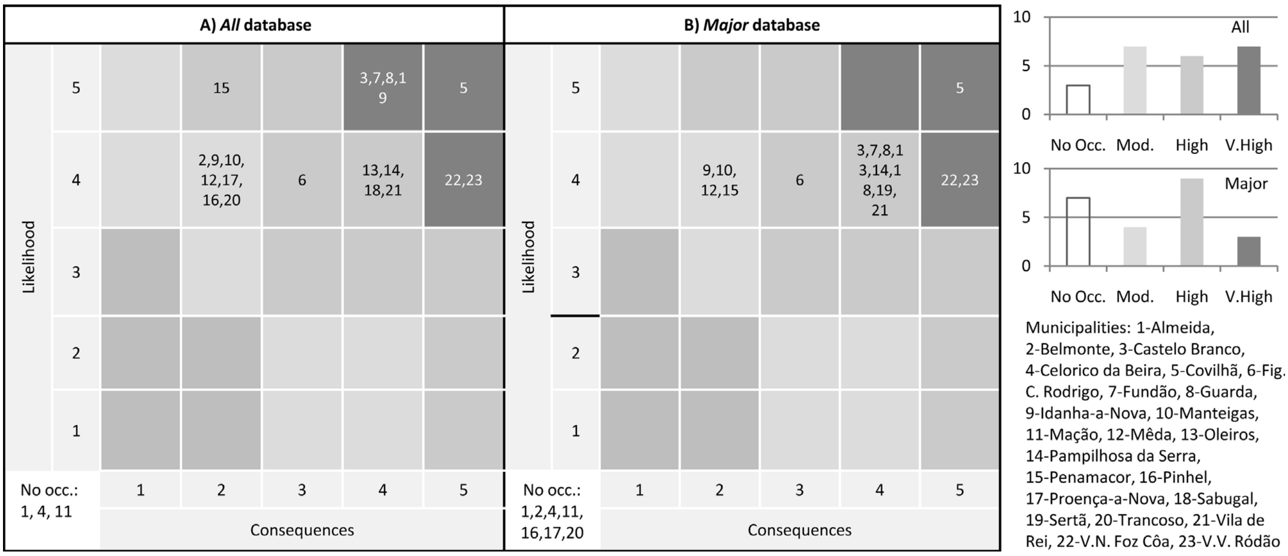

Fig. 6 – Risk matrices for hydro-geomorphologic disasters by municipality, from 1946 to 2010: *All* database (A), *Major* database (B) and respective histograms.

disaster occurrences, although this is not always evident and linear in the region as a whole.

Pearson correlations between the socio-economic territorial forcers considered and the impacts registered in the 23 municipalities are shown in Table 7. It can be seen that the correlation between the two variables expressing urban and demographic dynamics is significant (0.890), as well as the correlation between them and the number of *All* and *Major* type occurrences, although this is not significant when the absolute number of people affected is considered. This may suggest that the number of people affected – by death and disappearance, injury, displacement or evacuation – i.e. the severity of the loss, is somehow independent of urban and demographic dynamics, although the number of occurrences is not.

Considering the two groups of variables in Table 7 – forcers and impacts – the k-means clustering method was applied to the 23 municipalities. The impact cluster analysis considered all the variables shown in italics in Table 7: the number of *All* occurrences, number of *Major* occurrences, number of injured, deaths and missing people, number of displaced and number of people evacuated. The forcers cluster analysis considered the variables in bold: population change from 1950 to 2010 (%) and housing change from 1950 to 2010 (%).

The membership distribution of the impact clusters (cf. Fig. 10A) highlights the influence of extreme values, isolating four municipalities which present higher values in some of the variables considered, namely:

- cluster 5 for Covilhã (#5), with regard to the high number of occurrences and the number of deaths;
- cluster 4 for Figueira C. Rodrigo (#6), with regard to the high number of people evacuated;
- cluster 3, which contains 19 of the 23 municipalities but reflects heterogeneous impact contexts;
- cluster 2 for Fundão (#7), with regard to the high number of *All* type occurrences;
- cluster 1 for V.V Ródão (#23), with regard to the high number of missing people but low number of occurrences (cf. Table 4).

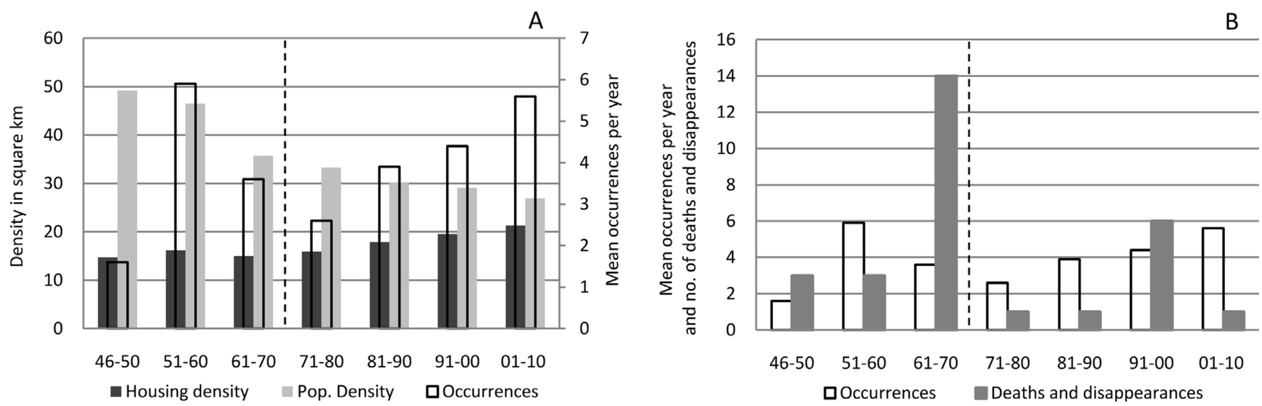

Fig. 7 – Relationship between *All* occurrences, housing density, population density (A) and severe human consequences (B).

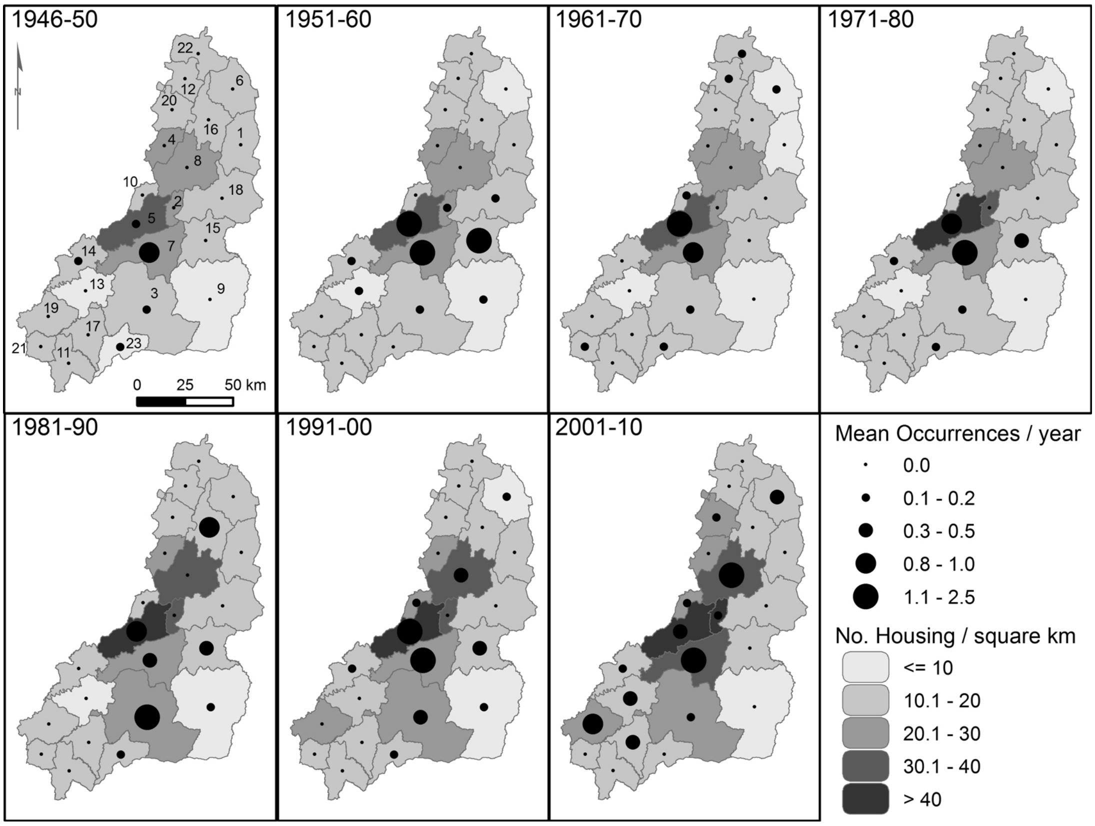

Fig. 8 – Temporal changes in housing density and hydro-geomorphologic disaster occurrences by decade, from 1946 to 2010.

Impact clustering may not accurately represent consequences and likelihood as they are expressed in the risk matrices. This inference is supported by the number of municipalities in cluster 3 which contains municipalities with distinct impact characteristics, as exemplified by V.N. Foz Côa (#22) where a high number of casualties can be found. In fact, in terms of the losses and damages reported, municipalities #22 and #23 present similar patterns – as pointed out when the risk matrices were analysed – but are represented in different impact clusters. Moreover, cluster 3 includes municipalities that present different classes of risk: Mação (#11), which shows no occurrences, together with municipalities such as Castelo Branco (#3) and V.N. Foz Côa (#22) that have "high" and "very high" classifications in the risk matrices.

The territorial forcer clusters (cf. Fig. 10B) express distinct regional dynamics, classifying the 23 municipalities according to levels of decrease and increase in population and housing, respectively. In this sense, cluster III identifies the most densely populated municipalities that present both a small decrease in population and a strong increase in housing (municipalities #3, #5 and #8, cf. Fig. 9A and B). Clusters I, II, IV and V reflect intermediate combinations of population decrease and housing growth. Cluster II, for example, includes Belmonte, Manteigas and Sertã (#2, #10 and #19, respectively), which register a high increase in housing and an intermediate decrease in population.[2] Cluster IV contains municipalities with an accentuated demographic decrease and a slight housing increase (#4, #6, #9, #11, #12, #13, #15, #22 and #23).

4. Risk profiles

The region is characterised by a landscape of hazards, impacts and urban and demographic dynamics that can be expressed as risk profiles, based on the information previously produced (Table 8). The definition of risk profiles result from a crossed interpretation of impacts and forcers cluster with risk matrices classification and range from "A" to "G", reflecting the ascending impact contexts for loss and damage and the respective urban and socio-economic contexts in which they occur. Profile "A" represents the safest municipalities in terms of hydro-geomorphologic related disasters, while profile "G" represents municipalities with the higher degree of losses and damages. For each profile, a demographic and urban context is associated.

The "A" profile corresponds to the safer municipalities in terms of hydro-geomorphologic related disasters. These are the municipalities that show no occurrences in both databases during the 64-year period of analysis, together with a significant decrease in population and a slight increase in housing density. Profile "B" is quite close to this in terms of rurality, but some minor damage is registered in the *All* database. Profile "C" municipalities present "moderate" risk

[2] In Sertã (#19), this urban and demographic dynamic was accompanied by an increase in mean annual occurrences in the last decade (cf. Fig. 8).

Table 7 – Pearson correlation between variables representing territorial forcers (in bold) and reported occurrences and impacts (in italics).

	Pop. Change 1950–2010	**Hous. dens. Change 1950–2010**	*# All occurr.*	*# Major occurr.*	*# deaths and disapp.*	*# injured*	*# displaced*	*# evacuated*
Pop. Change 1950–2010	1	0.890**	0.465*	0.458*	0.233	0.286	0.330	−0.045
Hous. dens. Change 1950–2010		1	0.411	0.504*	0.261	0.332	0.370	−0.210
# All occurr.			1	0.730**	0.509*	0.580**	0.613**	−0.011
# Major occurr.				1	0.844**	0.937**	0.877**	0.112
# deaths and disapp.					1	0.896**	0.684**	0.020
# injured						1	0.833**	0.067
# displaced							1	−0.001
# evacuated								1

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

in both risk matrices, with the exception of municipality #15 which only differs from the rest in terms of the higher likelihood in the *All* database. In addition, no deaths or missing persons are registered in any of the ''C'' municipalities and the rural visage is also a common feature. The ''D'' profile contains the municipalities that show ''high'' risk in both risk matrices, reflecting the existence of deaths and disappearances. Figueira C. Rodrigo (#6) is almost unique in this profile since it registers very few events and occurrences and no deaths or missing people, only evacuated people. All the ''D'' municipalities have strong rural characteristics.

The ''E'' municipalities are marked by strong urban growth between 1950 and 2010. They have in common the change from ''very high'' risk in the *All* matrix to ''high'' risk in the *Major* matrix - municipality #19 differs from the rest because it is an emerging municipality, i.e. it has only registered occurrences in the last two decades. All the municipalities registered one death. Fundão (#7) is a slightly different from the other ''E'' profile municipalities because although it has only one reported death, it has much more pronounced urban characteristics, reflected in the high number of occurrences resulting in property and material damage.

The ''F'' profile expresses two peculiar situations. Municipalities #22 and #23 are not among the most urbanised, as is confirmed by the small number of *All* type occurrences. However, the few occurrences registered are marked by serious human consequences associated with the proximity of two major rivers (the Douro and the Tagus). Finally, as may be concluded from the cluster membership, Covilhã (#5) is classified as an outstanding municipality in terms of the number of both types of occurrences and the mortality rate. It has the most severe risk profile ''G'', explained at least partially by a substantial urbanisation process taking place on hilly slopes and V-shaped valleys.

5. Discussion

The two compiled disaster databases – *All* and *Major* – differ significantly due to the criterion for the inclusion of disaster occurrences. It was also observed that the geographical coverage of newspapers is a relevant factor, influencing the levels of accuracy and completeness of the disaster database. This raises the question of the type of loss and damage data that might be lost when narrow inclusion criteria are defined for global disaster databases such as the EM-DAT.

The *All* database allowed disaster occurrences of higher frequency and low severity to be incorporated into the impact analysis. The benefits of this more holistic approach questions the emphasis placed on rare occurrences and offers an insight into the relevance of minor loss and damage occurrences – the ''small disasters'' – whose accumulated effects have serious economic impacts in the long term as well as major disasters (López-Peláez and Pigeon, 2011; Marulanda et al., 2010).

The construction of the risk matrices also underlined the importance of considering the regional press and more inclusive criteria in disaster databases. The *Major* database produced a risk matrix with lower risk in comparison to the one obtained from the more inclusive *All* database.

In short, this study showed that disaster databases based on newspaper reports have the potential to characterise the historical occurrence of hydro-geomorphologic disasters thoroughly, improving knowledge of their respective location, probability and severity.

As for the urban and demographic dynamics, the apparent contradiction of a decreasing population and an increase in housing is related to the internal and external migration phenomena reflecting the abandonment of rural settlements and concentration in the main urban areas (CCDRC, 2011), especially the main city in each municipality. These urban and demographic patterns may explain the increase in the number of *All* occurrences in the study area as a result of the greater exposure of people and assets in hazard areas (see also Fuchs et al., 2013), a process that has been occurring in Europe, in particular from 1970 to the present (Barredo, 2009). On the other hand, the reduction in the number of casualties after 1970 is possibly associated with other factors: the implementation of more holistic and robust emergency response systems, particularly in the last decade, the improvement of road network and water stream bridging and the decline in rural activities. These last two factors are associated with the contexts in which most of the deaths and disappearances occur. In fact, the occurrence of the most severe disasters does not only correlate with the densification of the human presence: this conclusion is supported by the fact that certain less urbanised municipalities such as V.N. Foz Côa (#22) and V.V. Ródão (#23) present disaster records that placed them in the highest risk classification in both risk matrices. This

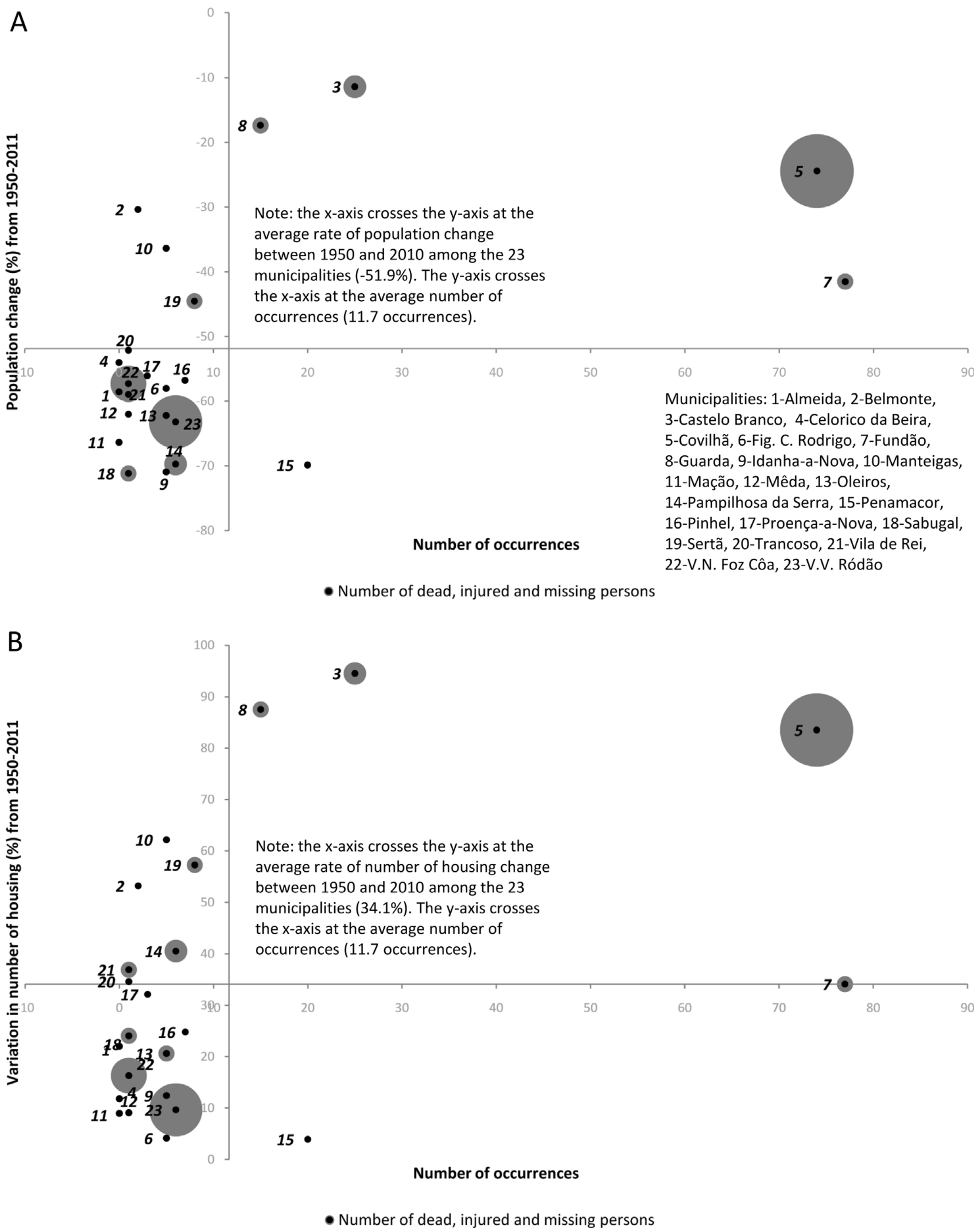

Fig. 9 – Relationship between number of occurrences, population and urban growth. Diameter of circles represents the most severe human losses.

means that the most populated and urbanised municipalities contain the greatest number of disaster occurrences, although when only major losses are considered, other peripheral municipalities emerge as high risk.

Extreme events are highly accounted for in risk matrices and cluster membership, as evidenced in several municipalities, and are particularly relevant in Figueira C. Rodrigo (#6). This municipality presents only 2 *Major* type occurrences but one of them resulted in the evacuation of 200 people in a unique flood event (January 2, 1962). Apart from this, the municipality presents no other human consequences except 2 people evacuated in another event.

The strategies and practices adopted by each municipality in their land use and risk management instruments must not be indifferent to the achieved risk profiles. Municipalities that present high probability of occurrence of loss and damage should consider the management of hydro-geomorphologic hazards in specific municipal risk management planning instruments. This is especially valid for Covilhã (#5) which beside a high probability also presents serious human and material consequences. Other municipalities present casuistic occurrences but with severe human consequences. For them, special planning instruments might not be useful, while the response to these types of hazards can be integrated in

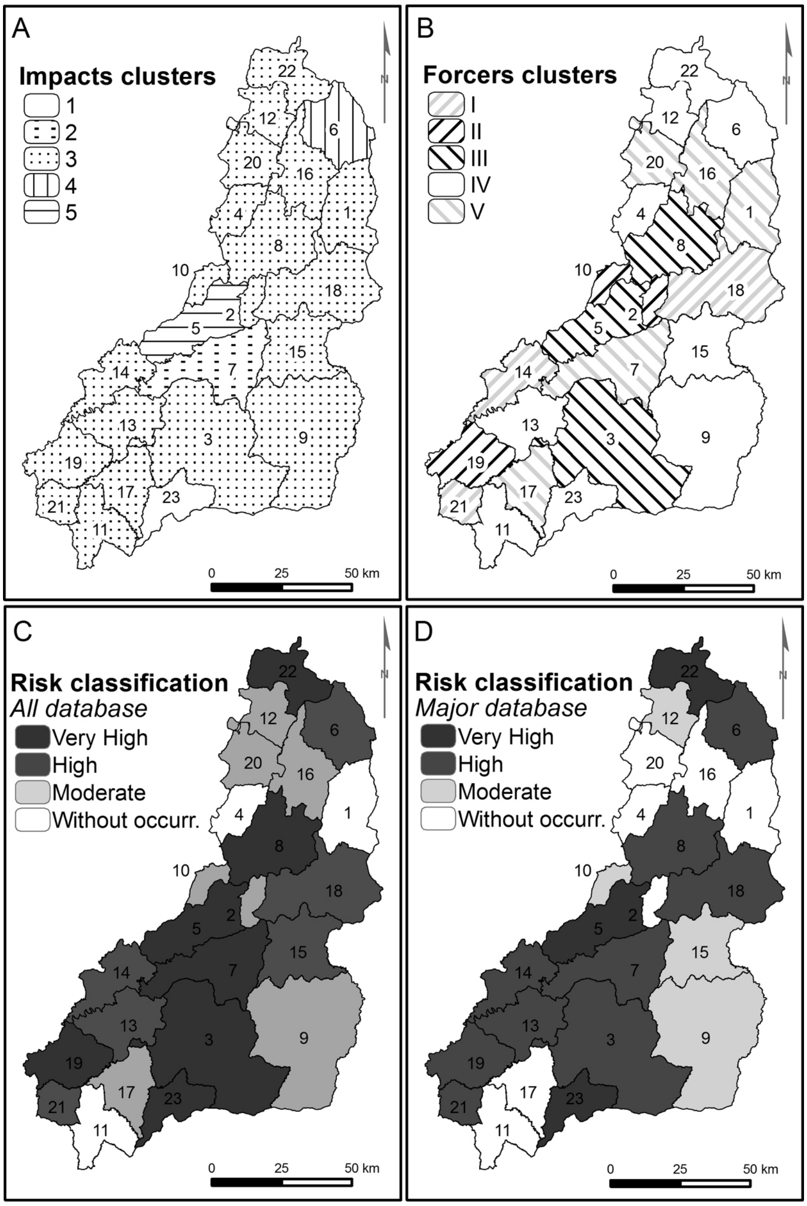

Fig. 10 – K-means cluster membership from impact variables (A), urban and demographic dynamics (B) and risk matrix classification according to the All database (C) and the Major database (D).

multi-risk plans. Nevertheless, localised structural interventions may be pondered considering that casualties are commonly associated to critical points such as stream crossings, and insurance and mutualisation solutions for human losses and material damages. Finally, for the majority of the municipalities human consequences consist of displacement and evacuation of a reduced number of people, and material and property damages. In this case, a multi-risk planning approach and a focus on land use instruments must address these impacts. In fact, single and local interventions in the natural systems have the potential to affect both positively and negatively the expression of hazard alone (Santos et al., 2011). In short, the results provide data to support not only small structural measures that reduce risks locally, but also broader approaches, such as (a) the optimal allocation of emergency response resources in the region, (b) adaptations to municipal master plans, taking the recurrence and severity of occurrences into account, (c) the planning of disaster preparedness and resilience measures on a community level, (d) the implementation of early warning systems and (e) feasibility studies for insurance solutions.

Such risk management options are framed in the European and national policy and instrumental building, mainly in the spheres of spatial planning and emergency planning, but also with regard to sectoral instruments (e.g. health, economy, conservation, energy or forestry). By its pertinence and actuality, the Flood Risk Management Plans, to be concluded by the end of 2015, foreseen in the EU Directive 2007/60/EC and in its transposition to the Portuguese legislation (Decree-Law 115/2010) deserve particular relevance as shift-driving forcers in the risk management paradigm.

Table 8 – Risk profile by municipality based on cluster analysis and interpretation of risk matrices.

	Municipality	Impacts cluster	Forcers cluster	Risk matrix *All/Major*	Risk profile
1	Almeida	3	V	–/–	A
2	Belmonte	3	II	M/–	B
3	Castelo Branco	3	III	VH/H	E
4	Celorico da Beira	3	IV	–/–	A
5	Covilhã	5	III	VH/VH	G
6	Fig. C. Rodrigo	4	IV	H/H	D
7	Fundão	2	V	VH/H	E
8	Guarda	3	III	VH/H	E
9	Idanha-a-Nova	3	IV	M/M	C
10	Manteigas	3	II	M/M	C
11	Mação	3	IV	–/–	A
12	Mêda	3	IV	M/M	C
13	Oleiros	3	IV	H/H	D
14	Pampilhosa da Serra	3	I	H/H	D
15	Penamacor	3	IV	H/M	C
16	Pinhel	3	V	M/–	B
17	Proença-a-Nova	3	V	M/–	B
18	Sabugal	3	I	H/H	D
19	Sertã	3	II	VH/H	E
20	Trancoso	3	V	M/–	B
21	Vila de Rei	3	I	H/H	D
22	V.N. Foz Côa	3	IV	VH/VH	F
23	V.V. Ródão	1	IV	VH/VH	F

6. Conclusions

The findings of this regional study demonstrate the relevance of incorporating all types of impacts – the *All* database as a complement to the *Major* database – in a hydro-geomorphologic disaster database. This is clearly evident when the mean occurrences per year in the *All* database are related to housing and population changes over the decades. On the other hand, the most severe human consequences – deaths and missing people – showed no correlation with these territorial forcers. In short, the region is facing a greater number of occurrences but with a smaller degree of severity in terms of human losses.

The study culminated in an attempt to classify the 23 municipalities according to a defined risk profile which not only refers to loss and damage characteristics but also combines them with urban and demographic dynamics in recent decades. In addition, the study contributes to our understanding of how combinations of these forcers change over time and how this is, or is not, reflected in the historically reported losses and damages.

One of the limitations of most disaster databases is that they only address tangible losses and damage and never consider intangible ones. Nevertheless, disaster databases constructed from newspaper records have the potential to improve the application of methodologies such as ALARP – "as low as reasonably possible" – F–N curves and risk matrices.

Risk and land use management face the challenge of understanding the relationship between the geophysical processes that create hazards and the impacts they cause. This being the case, is it more important to study the frequency of hazardous process or the frequency of the loss and damage associated with these processes? In the latter situation, disaster databases play a very important role in helping us to understand the relationship between geographical contexts and historically reported losses and damages (e.g. the effects of land use changes). Moreover, disaster databases can also assist in defining the severity thresholds – of a socioeconomic, urban and demographic nature – that trigger a given level of impact.

This is an innovative approach which allows using hydro-geomorphologic disaster databases for local strategies in risk management. The municipal profiles make possible different frames of action from specific emergency planning, warning and alert, multi-hazard planning, or prevention measures involving land use planning or insurance and mutualisation solutions.

This study has contributed to the future discussion on the extent to which risk decision-makers can benefit from disaster databases. Our conclusion is that both applied databases proved complementary to differentiate local distinct patterns of impacts – and their respective contexts – and contribute to define locally adequate risk management policies.

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Anexo B3 – Trabalhos de Investigação Originais: Caminhos e desafios para a gestão do risco de cheias e inundações

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Article

Basin Flood Risk Management: A Territorial Data-Driven Approach to Support Decision-Making

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Abstract: This paper explores the applicability of flood impact databases in the flood risk governance process. This study begins with a twofold analysis of three hydrographical basins: one analysis based on the data of a recently constructed flood-impact database for Portugal and another based on selected socioeconomic and biophysical variables that characterize the basins' territorial context. From these sets of data, two fuzzy inference systems are assembled: one for the resource criteria and another for the time criteria. When plotted, the fuzzy analysis results are associated with distinct flood risk management strategies: operational and strategic, hard and soft measure-based. The three basins differ substantially in terms of flood-impact characteristics, with impacts being distinguished in terms of human and material consequences. Socioeconomic factors seem to be more explicative of flood impacts than the biophysical contexts that generate floods. The fuzzy logic analysis suggested priorities of action: early warning and information for one of the basins (Mondego) and a less operational solution, combining structural mitigation and land-use planning, for the other two basins (Lis and Vouga). Considering the current implementation of the Floods Directive, design of flood risk maps and flood risk management plans can benefit from the integration of the presented methodology.

Keywords: impact; database; territorial context; fuzzy analysis; risk management

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1. Introduction

1.1. Contextualization

River basin management is discussed according to distinct perspectives seeking compromises between hydrologic, agronomic, ecologic and economic sustainable objectives (e.g., [1–3]). The need to harmonize the non-consumptive uses of water—among them flood risk management—and the consumptive uses of water demands a change in the way water management is conducted. This change must consider hydrological boundaries in an integrated approach following the principles of subsidiarity and stakeholder participation [4,5].

The European Water Framework Directive provides the institutional arrangement that is necessary for addressing the planning and management problems that are described by [6] although not considering specifically the flood risk [7]. Thus, the current and future instrumental framework for flood risk management derives from the implementation of the EU Directive 2007/60/EC, the "Floods Directive" [8], which assumes a drift from the solutions that are intended to keep the floodwaters away from the floodplain to the spectrum of non-structural solutions, at the basin scale, which addresses the capacity of natural and social systems to adapt to, respond to and recover from flood disasters [9]. Such a drift in flood risk governance from "flood protection to flood risk management" [10] (p. 510) is recognizable regarding three developments: (1) a shift from an engineering perspective, which is intended to prevent flooding by considering design flood events, to a management perspective, which aims to be prepared for supra-standardized events and assumes the "living with floods" attitude, which leads to action in the vulnerability component of the risk equation; (2) the outset of risk-informed decision-making, which ponders the costs of available options and assesses proportionate responses to risk according to a cost-benefit analysis (*cf.* [11]); and (3) the replacement of a risk reduction fragmented approach by an integrated systems approach where hard flood defenses are complemented or replaced by measures that mitigate flood impacts [10]. These shifts are crystallized in the EU "Floods Directive".

The challenges posed to flood risk management at the basin scale include the necessity to deal with uncertainty regarding the probability of events and the severity of their impacts, finding the combination of flood management strategies that provide the best results under an acceptable risk [12,13]. Spatial planning plays a central role in the flood risk management cycle—connecting sectors such as civil protection, environment, industry or transport, although its benefits in flood risk management can be highly variable or even present a missing role [14]. An operational emergency response with a strong focus on the development of technologies and tools for effective early warning systems [15] are also key features of this new framework.

The holistic perspective which embraces the "Floods Directive" constitutes an opportunity to further develop flood risk management at the basin scale in Portugal, although some nonconformities are identified in terms of (a) the mismatch between management and operational resources and (b) the necessity to improve the relationship between the stakeholders who manage the water resources (energy, irrigation, human consumption, ecology, *etc.*) and those who manage flood risk [16].

The methodology that is presented in this paper is an approach that informs risk managers—with territory data being the basis for decision-making—articulating water management and flood risk management at the basin scale. The effectiveness of risk governance processes depends on the quality of management strategies, which, in turn, are based on the conducted assessments. The presented approach is to be placed in the risk governance model linking judgment and management, filling this gap and proposing a methodology that analyses flood impacts and the territorial context in which they occur to provide relevant data that can support flood risk management decision-making.

Knowledge regarding flood impacts has become a priority, justifying the allocation of resources both from public and private stakeholders in the construction of impact databases not only for flooding but also for hazards in general [17]. Moreover, diverse motivations drive stakeholders to characterize disaster impacts, but less is still known about the rank of the type of data that is more relevant to be collected, although recent research on this subject has been conducted showing, among other findings, the relevance of expressing both direct and indirect damages in monetary terms [18] (p. 121). Additionally, flood impact data collection still lacks standardization and systematization [19,20]. Flood impact data are therefore initial inputs in the definition of risk management strategies, adequate to the river and basin contexts in which the impacts occur. Flood impacts vary according to the location of the exposed elements and their vulnerability and ability to resist, adapt and recover [10]. Assets at risk vary with socioeconomic scenarios that justify that the degree of flood impacts cannot be dissociated from the territorial context in which they occur, particularly with urbanization trends (e.g., [21,22]).

In this paper, flood risk management strategies are assessed using fuzzy inference systems (FIS). Scientific literature exemplifies the application of fuzzy logic in flood risk management with distinct purposes: e.g., real-time forecasting by modeling the rainfall-runoff relationship [23], flood-diversion planning [24], modeling the participation of multi-stakeholders in flood risk management decision-making processes [25], flood risk evaluation and flood risk response measures [26,27].

1.2. Research Goals

In summary, the main goal of this study is to analyze the degree to which the characteristics of different hydrographical basins shape the historical record of flood impacts and how this understanding can result in the production of scientific information with the ability to improve decision-making in flood risk management [28].

Three specific research goals are defined that are sequential in terms of the applied methodology: (1) the analysis and characterization of flood impacts in selected hydrographical basins; (2) the analysis of the relationships between these impact patterns and the territorial contexts and (3) the inference of flood risk management strategies through the application of fuzzy logic analysis as a decision-making tool.

1.3. Selected Region for Analysis

The selected region for this study consists of three hydrographical basins—Vouga, Mondego and Lis in Central Portugal. The total area of the three basins is 11,194 km^2 with an estimated population of approximately 1.5 million inhabitants [29], comprehending 86 municipalities and 753 parishes. This region historically registers a differentiation of flood impacts due to different natural and human territorial contexts. Recent dynamics in the following dimensions make the three selected basins an interesting region in which to test the above mentioned research goals:

(i) demographic changes: The area of the three basins is a territory of contrasted dynamics, particularly between a littoral more densely populated region and an inland region that is marked by ageing and depopulation. To a certain degree, this contrast is observed in the difference between Mondego basin's negative population growth and Vouga and Lis basins' positive growth (Table 1). In Mondego, 21 municipalities with positive growth are located mainly in the coastal, downstream sector of the basin.

Table 1. Recent dynamics in the three selected basins.

Basin	Pop. Growth 2001–2009 (%)	Municipalities with Positive Pop. Growth 2001–2009	Wild and Forest Burned Areas 1990–2009 (%)
Vouga	+3.12	58.1% (18 in 31)	18.2
Mondego	−0.03	45.7% (21 in 46)	36.5
Lis	+7.06	88.9% (8 in 9)	18.4

(ii) urban concentration: Along with urban growth in coastal areas, a decrease in the population of rural settlements is observed everywhere, with people increasingly concentrating in the seat of the municipalities, causing the rapid urban sprawl in medium to small cities and the marked depopulation of small villages. This decrease is particularly significant in the Mondego basin.

(iii) land use changes: As a part of the above processes, agricultural land is reducing, and forest and semi-natural areas are increasing. Additionally, significant areas of each basin (Table 1) were recently affected by wild fires—the Mondego basin being the most affected (36.5% of total basin area), with consequences in the basin hydrological runoff processes.

(iv) water management: Water management in the study area is currently performed at several administrative and sectorial levels. The Vouga, Mondego and Lis basins are part of the same Hydrographical Basin Management Plan (PGBH). This instrument identifies the entities to which each distinct competence (planning, management, licensing, supervision and monitoring) is attributed [29]: (a) national level: Portuary Authority (AP), National Forestry Authority (AFN), Environmental and Spatial Planning General Inspection (IGAOT), Portuguese Environment Agency (APA), Nature and Biodiversity Conservation Institute (ICNB), and Environmental and Conservation Service (SPNA); (b) regional level: Regional Hydrographic Administration (ARH) and Coordination and Regional Development Commission (CCDR); and (c) local level: Local utilization and concession associations (e.g., irrigation and forestry) and municipalities. Several other governmental bodies assume responsibilities in the basin area, regarding fields such as civil protection, health, energy, geology, agriculture, industry, and R & D, both public and private. In total, the management of the three basins is performed by 39 entities with a seat at the Regional Hydrographic Council, representing distinct private and public administration sectors, acting at different geographical levels.

(v) flood risk management: This competence is addressed at the regional level through the PBGH. Each municipality develops multi-risk emergency plans in which flood risks are addressed according to the historical, political and social perception of the risk. For example, Coimbra municipality has a specific emergency plan for floods, but the majority of municipalities do not. The implementation of the Floods Directive [8] is currently in the phase of flood risk assessment, while flood risk management plans are to be completed until the end of 2015. Municipal spatial planning plays a relevant role in risk adaptation and mitigation. Structural flood defenses exist in some of the basins, with 23 dams being classified in terms of risk for population and assets in case of rupture, 14 of which are located in the Mondego basin, 9 in the Vouga basin and none in the Lis basin.

This context and the availability of flood impact data from a recently constructed national disasters database [30] stress the pertinence and challenges of flood risk management at the basin scale.

2. Data and Methods

2.1. Flood Impact Data and Analysis

The DISASTER project [30] provides an unprecedented set of hydro-geomorphologic-related disasters in Portugal, from which flood impact data were collected for the three basins: Vouga, Mondego and Lis.

The temporal scope of the collected data is the period 1930–2010, which is a sub-period of a wider one (1865–2010) that is covered in the DISASTER database. Because the press is the main information source of the database, the selected 80 hydrological years are considered the most robust in terms of regional and national newspaper coverage for the study area—the most relevant regional newspaper, “Diário de Coimbra”, was founded in 1930.

Each record in the DISASTER database is defined has an occurrence, meaning the geographically identifiable place where a harmful process related to flooding took place. The extracted data for this study consider only flood impacts that are caused by fluvial inundation both in rural and urban areas. Coastal flood impacts are not included.

Two categories of occurrences with impacts are considered: occurrences in which human consequences (OHC) are reported, which includes death, injury, disappearance, displacement or evacuation of one or more persons, and occurrences in which uniquely material consequences (OMC) are reported such as impacts in facilities and properties (e.g., farmland; road networks; commercial, industrial and residential buildings; and educational, health and public administration buildings). OMC are naturally more frequent than OHC.

An analysis of impacts from both of these databases is performed via the calculation of basic statistical output, such as histograms regarding the spatial and temporal distribution of occurrences and their characteristics. The historical mean recurrence interval (HMRI) ([31], also used in [32]) which represents the average time lapse between two occurrences is calculated. F-N curves (*cf.* [33] and, specifically regarding flood risk, [34]), expressing the relation between the frequency of a given OHC and the number of persons affected by it, are also calculated.

2.2. Analysis of the Territorial Basins Context

The three basins are morphologically contrasting, reflecting a wide lithological diversity and structural complexity. In addition, relevant are the climatic variations along with seasonal flow regimes, diverse hydrogeological potentialities, and agricultural and forestry soil capacities. The societal system displays a set of demographic and socioeconomic heterogeneity which reflects in the unequal concentration of productive infrastructures and urban densities [35]).

In this study, a set of variables is selected that attempts to express each basin’s characteristics and specificities, accounting for their linkage with flood impacts and risk management. Variables defined according to hydrographical criteria, *i.e.*, at the basin level, are not abundant. Nevertheless, the PGBH presents a sufficient number of variables at that level that express the socioeconomic and hydrographical context, with the ability of differentiating the three considered basins (Table 2). Data from these 19 variables are compared by their normalized values (*i.e.*, z-scores, which were calculated using the software SPSS®, New York, NY, USA) and analyzed in terms of the Pearson correlations that they present among themselves, and with seven variables extracted from the two impact databases (OHC and OMC) (*cf.* Section 3.2). The results of this analysis are then used in the evaluation of two relevant criteria for decision-making.

Table 2. Variables considered in the analysis of the territorial basins context. Source: Hydrographical Basin Management Plan—Vouga, Mondego and Lis basins [29].

Socio-Economic Variables	Hydrographical Variables
1-Population density (Inhabitants/km^2)	I-Basin area (km^2)
2-Housing density (Houses/km^2)	II-Compacity Index (Kc)
3-Aging index	III-Drainage network length (km)
4-Population without qualifications (% of total)	IV-Drainage density (km/km^2)
5-Unemployment rate (%)	V-Average basin slope (%)
6-Purchase power (related to the national mean = 100)	VI-Average roughness coefficient
7-Annual turnover (€)	VII-Average annual rainfall (mm)
8-Density of companies (No. of companies per km^2)	VIII-Average annual flow (mm)
9-Urban soil (% of total basin area)	IX-Number of dams
	X-Flood prone area (% of total basin area)

2.3. Assessment of Flood Risk Decision-Making Criteria

Flood risk management is a complex process involving a large number of interveners and strategies. In this study, a simplification is made in order to consider only two of the diverse criteria that are used for supporting decision-making in flood risk management: time and resources. These criteria must be understood in relative terms between the three basins and under the perspective of their availability and necessity. Time and resources are relevant criteria in a wide range of management decision-making processes (a thorough variety of examples are provided in [36] and specifically in flood risk management (e.g., [28]), from which other sub-criteria can be defined—acceptability level, for example, is a criterion closely related to time. Time expresses both the available time to intervene and the necessary time to implement measures. Time can be defined as the opposite of urgency, *i.e.*, the higher the urgency the lower the time to act. Some flood risk management strategies take longer to be implemented while others can be implemented in the short term. Resources, as a criteria, expresses the necessary means to implement a given strategy or measure. Structural measures like flood defenses and dams usually require greater amount of resources than other strategies classified as "soft" measures. In a given risk management process, resources might exist at an adequate level to tackle the problem, but the decision regarding the time to act can be defined in a medium or long term if the problem is judged to be not urgent.

Fuzzy logic is widely applied in decision-making processes that deal with high levels of uncertainty and ambiguity [37]. In this study, two fuzzy inference systems (FIS) were therefore set up for the two criteria. The FIS is applied using the software FISPRO, which was developed by the French Institut National de la Recherche Agronomique (INRA) [38]. A FIS requires the definition of input and output data, and rules that express the possible combinations of the different input data values in order to obtain a given output.

In this application two FIS are set up: one for the time and other for the resources criteria. Input data for each of them are, respectively, the variables that express the necessity of resources and the characteristics of the impacts (*cf.* Table 3). The outputs are the two considered criteria. The variables used to represent the time criteria are, at first hand, representing urgency, e.g., the higher the casualties the higher the urgency. In order to achieve the crisp value for the criteria time, the resulting value is subtracted to 1 to express the time to act, *i.e.*, the greater the urgency, the lesser the available or desirable time to act in flood risk management. From the initial set of 19 variables that represent the territorial context (*cf.* Table 2), only 5 are used in the fuzzy logic analysis. This selection is based (i) on the interpretation of the role of each variable according to the criteria of resources and urgency and (ii) on the Pearson correlation values between the impact variables and the socio-economic and geophysical variables. The other 3 variables represent the characteristics of the flood impacts and were calculated from the raw fields of the considered OHC and OMC database: number of dead, disappeared, evacuated and displaced persons, and number of occurrences with human and material consequences (Table 3).

Table 3. Input data and respective decision-making criteria used in the FIS.

Input Data	Lis	Mondego	Vouga	Decision-Making Criteria
Basin area (km^2)	850.1	6658.6	3685.2	Resources
Purchase Power (national mean = 100)	84.00	67.00	73.00	
Population density (Inhabitants /km^2)	222.12	105.70	174.49	
Urban soil (% of total basin area)	7.50	2.40	5.70	
Flood prone area (% of total basin area)	2.47	2.66	2.52	Urgency
No. of dead and disappeared per10^5 Inhabitants	2.65	4.26	3.89	
No. of evacuated and displaced per 10^5 Inhabitants	99.03	225.91	75.42	
No. of OHC and OMC per km^2	0.24	0.33	0.19	

Fuzzification is the first step of a FIS in which input data values are transformed into membership degrees. The next step of the FIS consists in setting up inference engines based on rules that express different combinations of the selected variables under the perspective of the two criteria. For example, the population density is valued as a requisite for a low (1), medium (2) and high (3) need for resources. The rules express the relationship between the input variables using conditional statements, where values ranging 1 to 3 are summed. Therefore, each output value will theoretically range between 4 and 12, since each output is explained by four variables. According to the number of variables that represent input data 4 in each FIS, and the values they assume ranging from 1 to 3, a total of 81 rules are defined. Finally, the defuzzification step consists in introducing again the exact value of each basin (*cf.* Table 3) in the respective FIS and, according to the membership function defined by the rules, a crisp value between 0 and 1 is returned for each of the criteria. This step returns the position (low, medium or high) of each basin in terms of the resources and urgency criteria. As early explained, the crisp value of this later criterion is subtracted by 1 to express the time instead of urgency.

3. Results

3.1. Flood Impacts

Flood impacts are expressed in 3073 occurrences, of which 238 (7.7%) present human consequences (Table 4). In 753 parishes, only 282 registered any of the considered flood impacts, either material or human, in the 80-year period.

Table 4. Resume of flood impacts in the constructed databases.

Basin	No. OHC + OMC	No. OHC	No. Deaths and Disapp.	No. Evacuated	No. Displaced
Vouga	689	53	25	417	68
Mondego	2179	166	30	750	840
Lis	205	19	5	142	45
Total	**3073**	**238**	**60**	**1309**	**953**

The inter-annual distribution of these same variables is highly irregular (Figure 1A–D). Nevertheless, the number of occurrences seems to present a wave oscillation with fewer occurrences in the 1930s, partially in the 1940s, and again in the 1970s, 1980s and partially in the 1990s. This pattern is not as clear in the last two graphics (Figure 1C,D). In fact, the number of dead and disappeared persons (D & D) shows a decrease tendency during the period, while the number of evacuated and displaced persons (E & D) increased (Figure 2B–D).

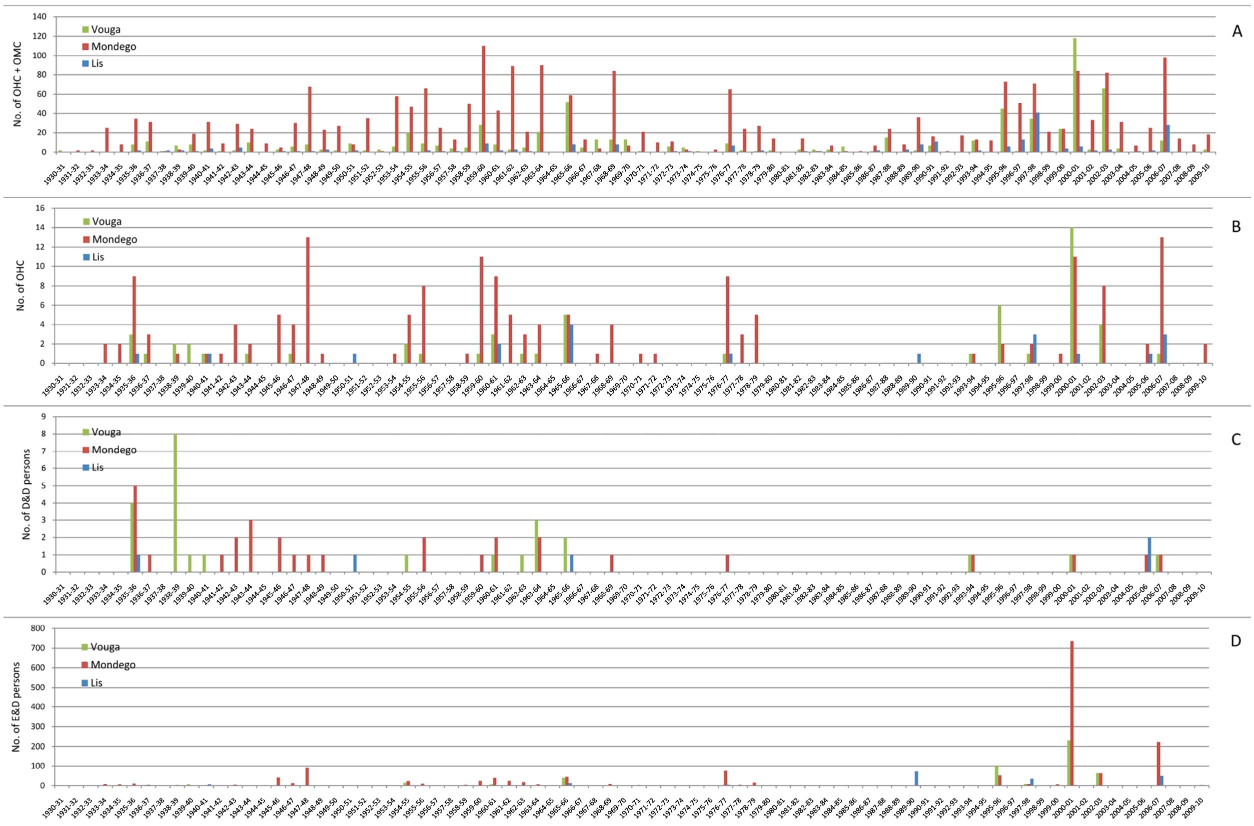

Figure 1. Inter-annual distribution of total occurrences (**A**); number of OHC (**B**); number of D & D persons (**C**); and number of E & D persons (**D**).

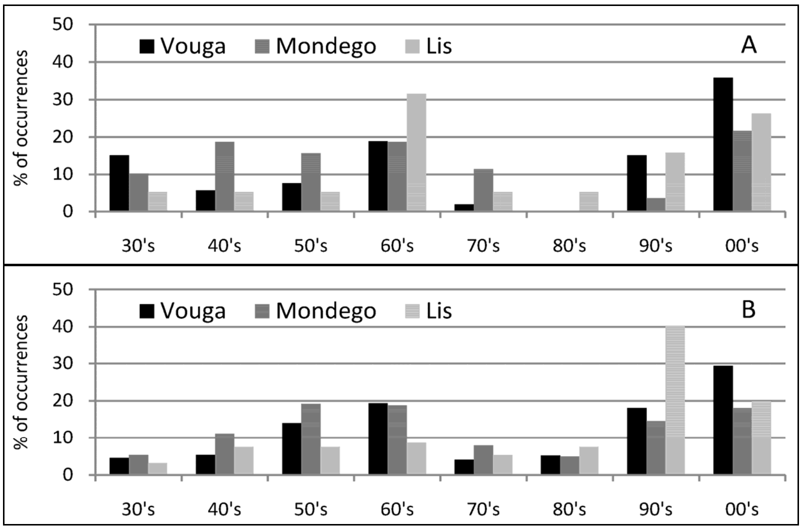

Figure 2. Relative frequencies by decade of the No. of occurrences with human consequences (OHC) (**A**); and No. of occurrences with only material consequences (OMC) (**B**).

Figure 2B confirms the general existence of two periods with a high No. of OMC: the 1950s and 1960s, and the 1990s and 2000s. The relevance of these last two decades is especially notable in the Vouga and Lis basins.

The Lis basin was more affected by OHC in the 1960s and 2000s, while OMC became more frequent in the last two decades. The worst decade for the Mondego basin in terms of the number of occurrences of both OHC and OMC was 2001–2010.

The number of occurrences is not, however, correlated with the number of affected people either by death, disappearance, evacuation or displacement (*cf.* Figures 3 and 4). The deaths and disappearances show a reducing trend, except in the Lis basin (although this basin only registered 5 D & D persons during this period), while the number of evacuations and displacements increased significantly in the last decade. This reading is generally confirmed by the relative frequencies (Figure 4A,B).

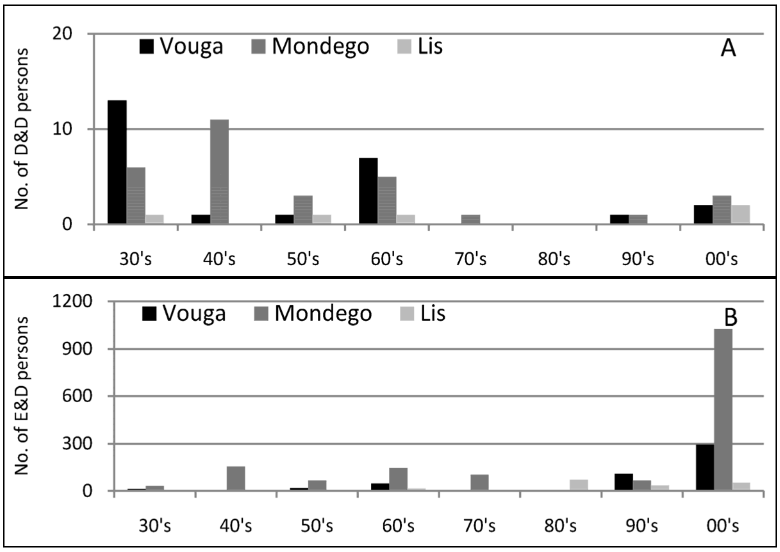

Figure 3. Absolute frequency by decade of dead and disappeared (D & D) persons (**A**) and evacuated and displaced (E & D) persons (**B**).

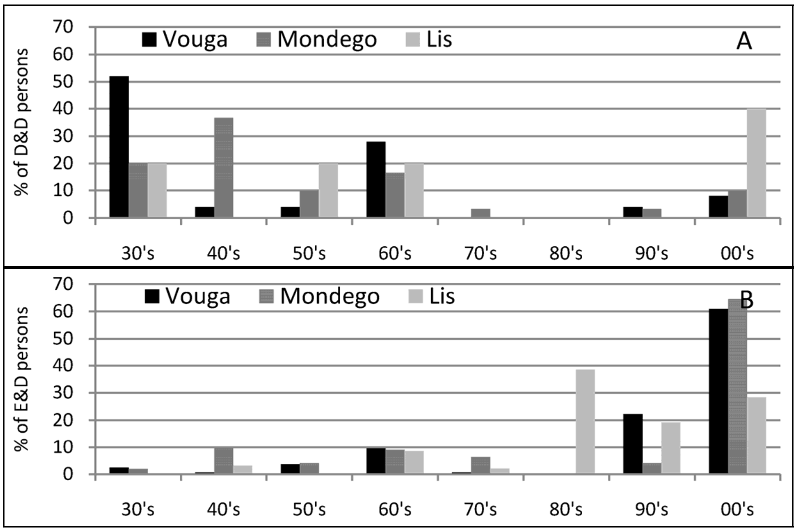

Figure 4. Relative frequency by decade of dead and disappeared (D & D) persons (**A**) and evacuated and displaced (E & D) persons (**B**).

In absolute terms, the Mondego basin presents the lowest HMRI, *i.e.*, the necessary number of years so that one D & D, one evacuated or one displaced person might occur (Table 5). With the exception of the occurrence of D & D in the Lis basin, the probability of registering at least one of these losses from the 5-year return period forward is always higher than 0.79. Evacuations are more frequent than displacements in the Vouga and Lis basins but not in the Mondego basin.

Table 5. HMRI and probability from 1 to 100 year return period of having at least one D & D, one evacuated and one displaced person.

Basins	**Variables**	***HMRI ****	**Probability by Return Period**					
			1-Year	**5-Year**	**10-Year**	**25-Year**	**50-Year**	**100-Year**
Vouga	D & D	*3.20*	0.268	0.790	0.956	1.000	1.000	1.000
	Evac	*0.19*	0.995	1.000	1.000	1.000	1.000	1.000
	Disp	*1.18*	0.573	0.986	1.000	1.000	1.000	1.000
Mondego	D & D	*2.58*	0.321	0.856	0.979	1.000	1.000	1.000
	Evac	*0.09*	1.000	1.000	1.000	1.000	1.000	1.000
	Disp	*0.10*	1.000	1.000	1.000	1.000	1.000	1.000
Lis	D & D	*16.00*	0.061	0.268	0.465	0.790	0.956	0.998
	Evac	*0.56*	0.831	1.000	1.000	1.000	1.000	1.000
	Disp	*1.78*	0.430	0.940	0.996	1.000	1.000	1.000
Three basins	D & D	*1.31*	0.534	0.978	1.000	1.000	1.000	1.000
	Evac	*0.06*	1.000	1.000	1.000	1.000	1.000	1.000
	Disp	*0.08*	1.000	1.000	1.000	1.000	1.000	1.000

Note: * HMRI: Historic Mean Recurrence Interval, in years (Coe *et al.*, 2000 [31]).

Considering the proximity and contiguity of the three basins, it is interesting to note the distinct monthly distribution of the percentage of OMC as well as of the number of D & D and E & D persons (Table 6).

Table 6. Absolute and relative frequencies of the number of D & D and E & D persons, and number of occurrences uniquely with material consequences (OMC), by month.

Type	Basins		October	November	December	January	February	March	April	May	June	July	August	September	Total
OHC: D & D	Vouga	Abs	1	0	4	12	6	1	0	0	1	0	0	0	*25*
		%	4.0	0.0	16.0	48.0	24.0	4.0	0.0	0.0	4.0	0.0	0.0	0.0	*100.0*
	Mondego	Abs	4	3	7	3	4	2	1	0	2	2	0	2	*30*
		%	13.3	10.0	23.3	10.0	13.3	6.7	3.3	0.0	6.7	6.7	0.0	6.7	*100.0*
	Lis	Abs	0	0	0	0	2	1	0	0	2	0	0	0	*5*
		%	0.0	0.0	0.0	0.0	40.0	20.0	0.0	0.0	40.0	0.0	0.0	0.0	*100.0*
OHC: E & D	Vouga	Abs	5	13	98	241	84	35	0	6	3	0	0	0	*485*
		%	1.0	2.7	20.2	49.7	17.3	7.2	0.0	1.2	0.6	0.0	0.0	0.0	*100.0*
	Mondego	Abs	260	26	106	1049	90	21	9	11	15	3	0	0	*1590*
		%	16.4	1.6	6.7	66.0	5.7	1.3	0.6	0.7	0.9	0.2	0.0	0.0	*100.0*
	Lis	Abs	50	36	75	6	18	0	0	2	0	0	0	0	*187*
		%	26.7	19.3	40.1	3.2	9.6	0.0	0.0	1.1	0.0	0.0	0.0	0.0	*100.0*
OMC	Vouga	Abs	58	70	99	229	95	29	17	17	11	1	4	6	*636*
		%	9.1	11.0	15.6	36.0	14.9	4.6	2.7	2.7	1.7	0.2	0.6	0.9	*100.0*
	Mondego	Abs	337	220	203	372	228	146	55	118	128	33	30	143	*2013*
		%	16.7	10.9	10.1	18.5	11.3	7.3	2.7	5.9	6.4	1.6	1.5	7.1	*100.0*
	Lis	Abs	56	32	19	11	10	8	5	4	4	2	3	32	*186*
		%	30.1	17.2	10.2	5.9	5.4	4.3	2.7	2.2	2.2	1.1	1.6	17.2	*100.0*

After summer, the number of OMC begins to increase earlier (in September) than does the number of OHC, particularly in the Lis basin. This pattern may require local planners and basin managers to define regular, seasonal measures of risk reduction and prevention. In general, OHC are more frequent from October to February, with the exception of November.

Based on the database of OHC, F-N curves were calculated (Figure 5). The worst hydrological years regarding D & D persons occurred in the Vouga basin—two OHC with four fatalities each—to which a 0.025 annual frequency is attributed. Mondego basin assumes preponderance in the OHC with one fatality. Regarding E & D persons, the three basins display similar patterns in the F-N curve regardless of the number of affected persons. Lis basin is the less severe in both cases in terms of these impacts.

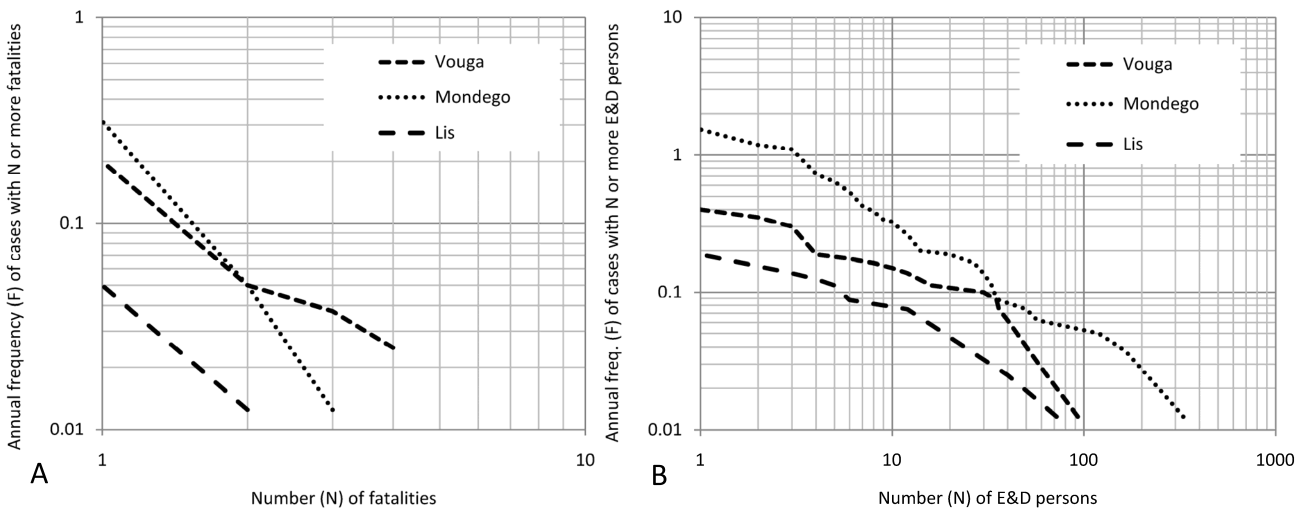

Figure 5. F-N curves for the number of fatalities (D & D) (**A**); and evacuated and displaced persons (**B**).

As expected, the geographical distribution of flood impacts in the three basins shows a strong localized and linear pattern, according to the location of the main floodplains and cities. This concentration is, however, more notable in relation to material impacts (OMC) than to human consequences, particularly regarding occurrences with casualties which occur more sparsely (*cf.* Figures 6 and 7). Of the 42 parishes with D & D persons, 15 are located in the Vouga basin, while this type of loss affects 4 parishes in the Lis basin and 23 in the Mondego basin.

Inside each basin, the regional dichotomy between the downstream and upstream areas is more evident in terms of D & D persons than with regard to evacuated and especially displaced persons. All of the occurrences with D & D persons that were described in newspapers allow for their georeferencing at least to the level of the parish, which allows concluding about the high completeness and quality of the database.

Figure 7 represents the number of times each of the six types of material impacts is mentioned. Impacts in roads are proportionally higher in the Mondego basin, while the Vouga presents a higher proportion of references to farmland impacts and the Lis in regard to residential building impacts.

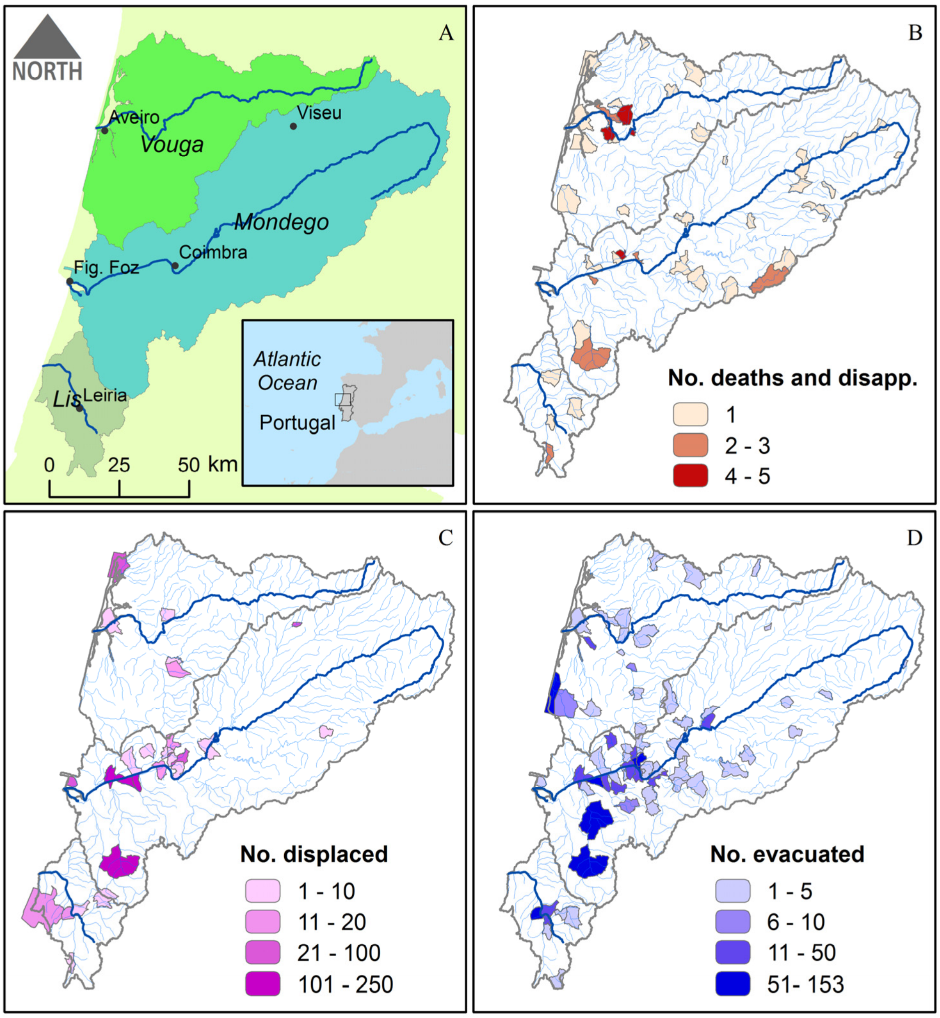

Figure 6. Relation between the main cities and rivers and the occurrences with human consequences, by parish, 1930/1931–2009/2010. (**A**) Vouga, Mondego and Lis basins; (**B**) No. of D & D persons; (**C**) No. of displaced persons; (**D**) No. of evacuated persons.

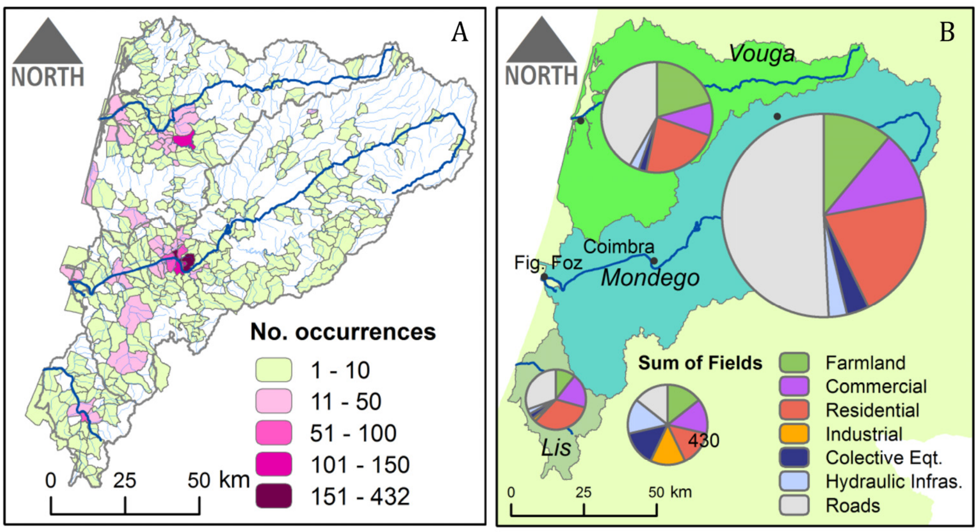

Figure 7. Occurrences with material consequences by parish (**A**) and type of material impact by basin (**B**).

3.2. Relationship between Flood Impacts and Basin Characteristics

The establishment of relationships between impacts and basin characteristics is attempted by analyzing the z-scores of the three considered categories of variables: socioeconomic and hydrographical context data, and impact data (Figure 8). In contrast, the Mondego basin presents the most serious impacts regarding both human and material consequences. Mondego is also the basin in which socioeconomic conditions are generally the worst—this basin presents the highest unemployment rates, lowest economic dynamics and purchase power, although it is not the most densely populated or urbanized. Hydrographical conditions seem to play unclear and opposite roles in the explanation of the registered flood impacts: while the Mondego basin presents the highest percentage of flood-prone area, mean slope, area and drainage length, some other variables should contribute to the attenuation of flood frequencies and impacts in this basin, such as compacity (higher Kc values tend theoretically to reduce peak flows), roughness coefficient and number of dams.

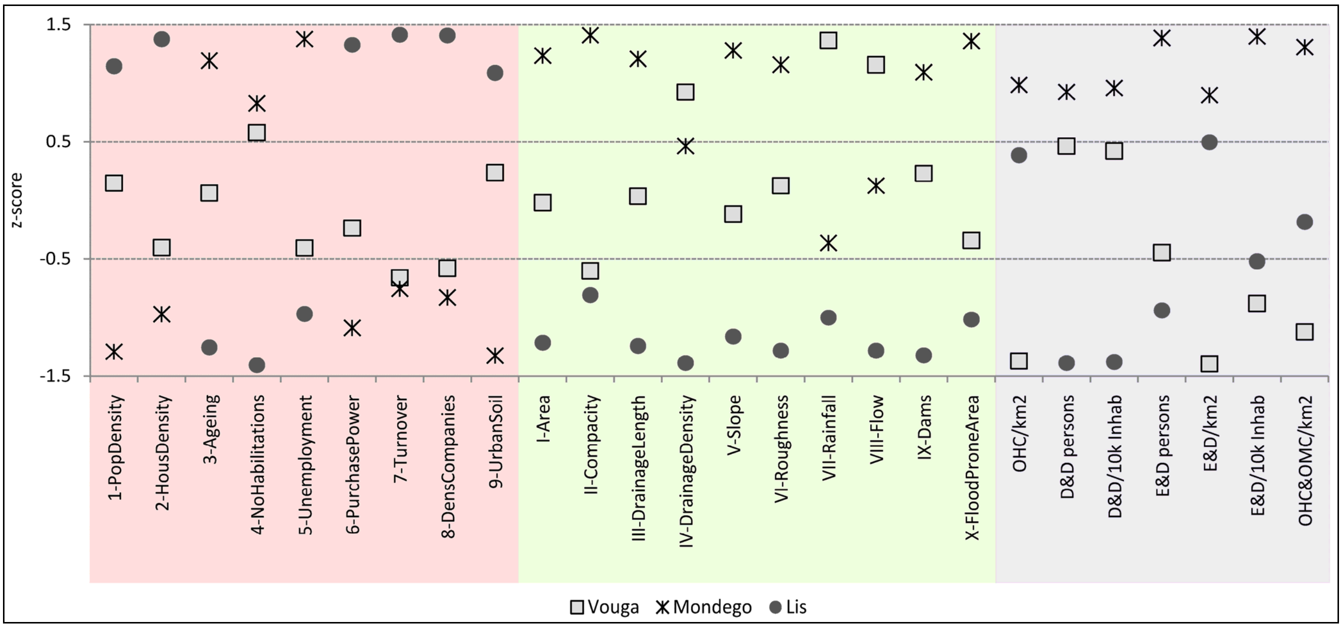

Figure 8. Comparison of Vouga, Mondego and Lis basins in terms of socio-economic (**red shadow**); hydrographic (**green shadow**) and impact variables (**blue shadow**).

Although the number of individuals is reduced, the Pearson correlation coefficients (Table 7) are significant between (1) variables that express urban and demographic dynamics and variables that are related to the distribution of mortality (D & D persons) and (2) flood-prone areas and the total number of E & D persons (but not when E & D is related to the area). In several other pairs of variables, the correlation is at least greater than 0.9. It is interesting to note that when the impact variables are related to the area (sq.km) or population (105 inhabitants), Pearson coefficients are weak, except for the number of D&D persons.

Figure 9 presents the relationship between the impacts, area and population. The area and population strongly define the pattern of the distribution of the number of occurrences—both total and OHC only—with a higher linearity regarding the area (Figure 9A) and an exponential type correlation regarding the population (Figure 9D). The total number of fatalities appears to be more correlated with the population than with the area (Figure 9B,E), although the opposite occurs regarding the frequency of occurrences with one fatality (Figure 9C,F).

Table 7. Pearson correlation matrix between territorial forcers and impact variables.

Variables	**No. of OHC Per km²**	**No. of OHC and OMC per km²**	**No. of D & D Persons**	**No. of D & D Per 10^5 Inhabitants**	**No. of E & D Persons**	**No. of E & D Persons Per km²**	**No. of E & D Persons Per 10^5 Inhabitants**
1-Population density	−0.35	−0.69	−0.91	−0.92	−0.98	−0.27	−0.84
2-Housing density	0.04	−0.36	−1.00 *	−1.00 *	−0.82	0.12	−0.57
3-Aging index	0.20	0.57	0.96	0.97	0.93	0.12	0.76
4-Pop. without qualifications	−0.17	0.23	1.00	0.99	0.74	−0.25	0.46
5-Unemployment rate	0.51	0.81	0.81	0.83	1.00 *	0.44	0.93
6-Purchase power	−0.08	−0.47	−0.99	−0.99	−0.88	0.00	−0.67
7-Annual turnover	0.24	−0.17	−0.99	−0.98	−0.69	0.31	−0.40
8-Density of companies	0.17	−0.23	−1.00	−0.99	−0.74	0.25	−0.46
9-Urban soil	−0.40	−0.73	−0.88	−0.89	−0.99	−0.33	−0.88
I-Basin area	0.26	0.62	0.94	0.95	0.95	0.18	0.79
II-Compacity Index (*Kc*)	0.64	0.89	0.72	0.74	0.99	0.57	0.97
III-Drainage network length	0.22	0.59	0.95	0.96	0.94	0.14	0.77
IV-Drainage density	−0.45	−0.06	0.93	0.92	0.51	−0.52	0.19
V-Mean basin slope	0.32	0.67	0.92	0.93	0.97	0.25	0.83
VI-Mean roughness coefficient	0.16	0.54	0.97	0.98	0.92	0.08	0.73
VII-Mean annual rainfall	−0.87	−0.61	0.56	0.53	−0.06	−0.91	−0.40
VIII-Mean annual flow	−0.65	−0.30	0.81	0.79	0.29	−0.71	−0.06
IX-Number of dams	0.09	0.47	0.99	0.99	0.89	0.00	0.67
X-Flood prone area	0.47	0.78	0.84	0.86	1.00*	0.40	0.91

Note: * Correlation is significant at the 0.05 level (2-tailed).

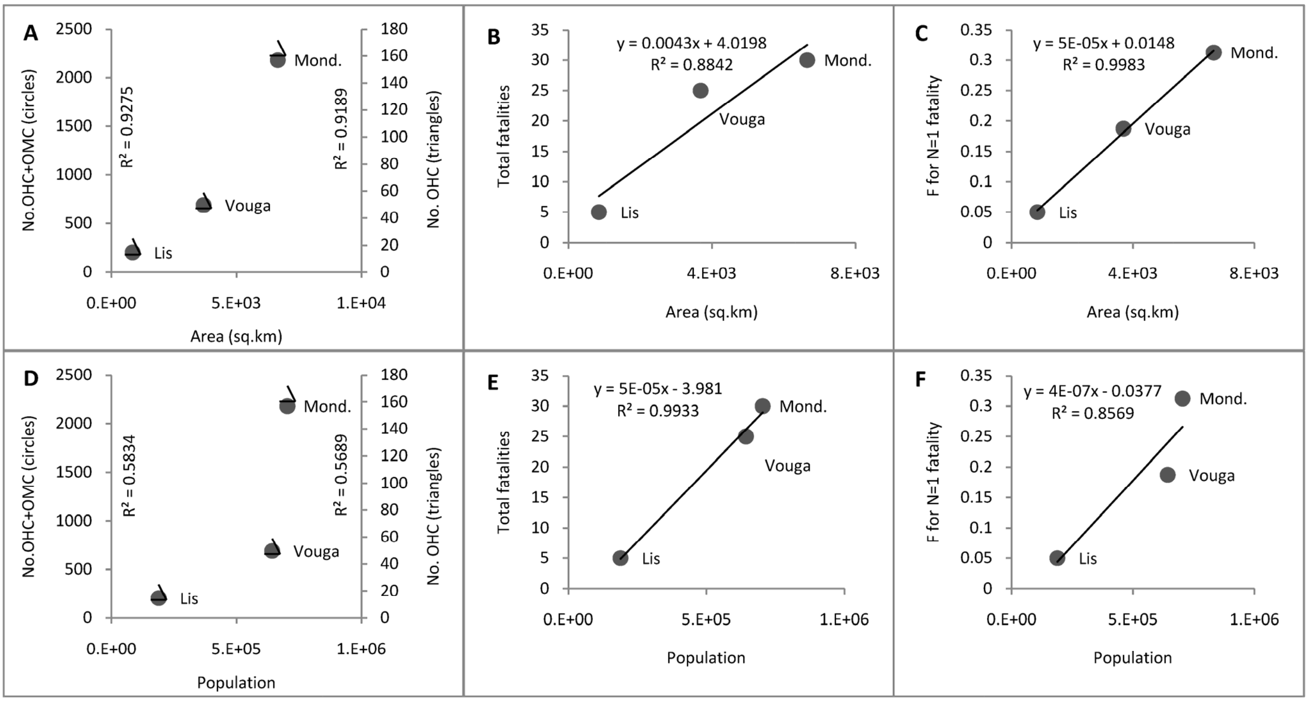

Figure 9. Relation between area and population and the number of occurrences (**A**,**D**); the number of fatalities (D & D persons) (**B**,**E**); and the frequency of occurrences with one fatality (**C**,**F**).

3.3. Criteria Evaluation for Flood Risk Management Strategies

The main output of this section is the result of the two designed FIS (Figure 10). This figure represents the crisp values that are returned for each criterion—Resources and urgency—Based on the established rules. Using the value that each basin presents in the considered variables, their respective degree of membership in terms of resources and urgency is returned. Therefore, for example, it is possible to verify that the Lis basin would comparatively be the most demanding in terms of resources, which is justifiable by the higher population density and urbanized area. Nevertheless, this basin is the least urgent in terms of addressing flood risk management because impact data, such as the No. of D & D persons and the No. of E & D persons per 10^5 inhabitants, do not represent the same seriousness of the other basins. Mondego basin features the opposite scenario in terms of these criteria: it is comparatively less exposed—*i.e.*, considering its higher area, it has comparatively less assets to protect—But human and material consequences represented by the No. of OHC and OMC and the No. of D & D and E & D persons per 10^5 inhabitants, as well as the percentage of flood-prone areas, are also comparatively higher, thus requiring more immediate action.

The presented results are further developed and discussed in the following section, where flood risk management strategies are identified and prioritized according to the position of the three basins in regard to these two outputs.

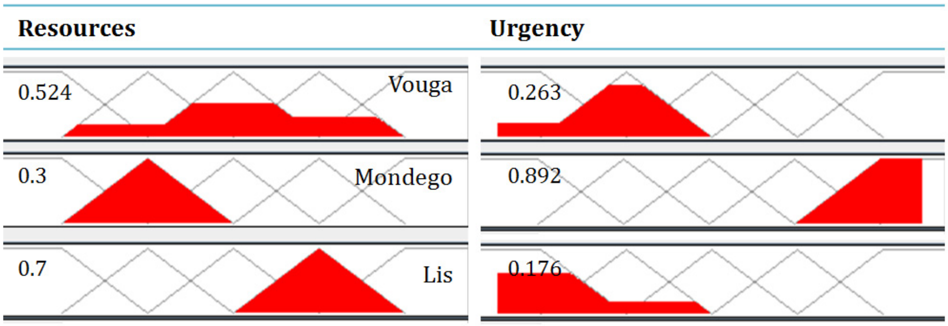

Figure 10. Defuzzification step using the FISPRO program.

4. Discussion

The discussion will focus both on the results and the adopted methodology.

A parallel between the risk governance components [39] and the research methodological approach that was followed in this study is illustrated in Figure 11. Flood risk governance is not obviously as simple as this representation may suggest (e.g., [40]); nevertheless, the purpose of establishing this parallelism is to support the relevance of visioning and to provide theoretical guidance over the entire research process from the point of view of risk governance.

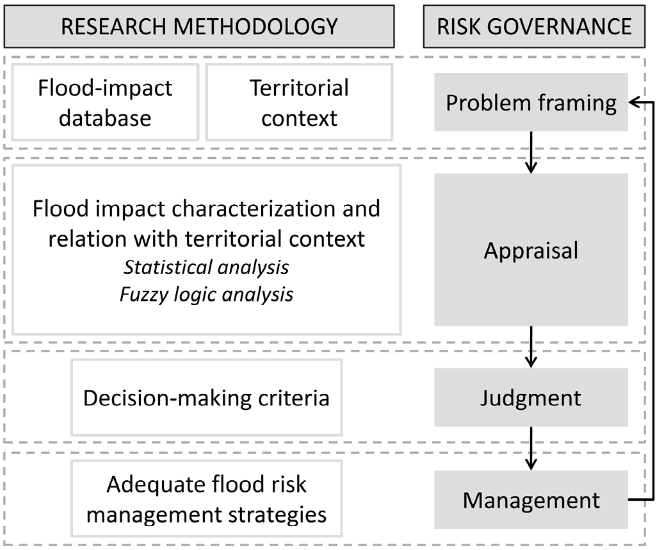

Figure 11. Risk management framework of the study methodological approach.

Cyclicity is a key feature of risk governance models. In the adopted methodology, cyclicity is understood as the continuous monitoring and evaluation of the efficiency of the preconized flood risk management strategies. This is achievable through basin differentiation based either on the updating of the flood impact database or on the monitoring of changes that occur in the territorial characteristics of the basin. Once again, many other factors (e.g., social, political and economic) influence the decision about flood risk management strategies; however, this fact does not negate the validity of the established correspondence.

Flood risk governance in Portugal is experiencing a shift within the implementation of the "Floods Directive", following a holistic approach combining assessment, management and participation benchmarks. Concerning the assessment component, the role of flood impact databases can be determined based on the perspective of the elaboration of flood risk maps. This type of databases assist in the characterization of the location, type and recurrence of a given set of impacts that can be incorporated in risk maps, adding value to the content required in the Floods Directive. However, caution must exist when using impact data in the cartography of flood hazard. This means, on the knowledge of the physical process of the flood and its probability, because the nature of impact databases is rooted on the consequence and not on the flood process.

Considering that a more operational use of historical impact databases by decision-makers is constrained partly by the lack of practical guidelines about their potential applications [41], the presented methodology can be further explored in order to assist the preparation of flood risk planning instruments. This lack is a concern also expressed in the UNISDR consultations regarding the post Hyogo Framework for Action 2005–2015, where a need to improve and standardize data-supported decision-making is identified [42].

One of the proposed research goals was the inference of flood risk management strategies through the application of fuzzy logic analysis as a decision-making tool. This attempt is illustrated in Figure 12, in which fuzzy membership crisp values for resources and time criteria are expressed. As referred in Section 2.3, the criteria time is derived from urgency.

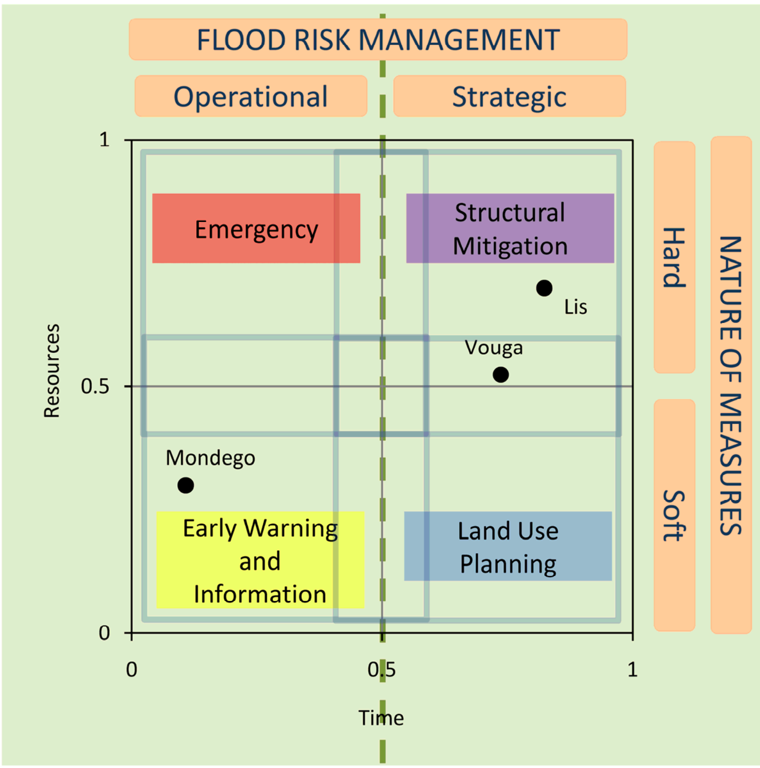

Figure 12. Inference of flood risk management strategies upon the FIS results.

The strategies presented in Figure 12 are classified according to the nature of the measure—hard and soft, and to the type of risk management—perational and strategic. The four considered strategies:

emergency, early warning and information, structural mitigation and land use planning are identified and recognized as major supporting tools in flood risk management (e.g., [43] (pp. 8–9), [44] (pp. 82–83)). Other strategies could be foreseen, such as insurance, but the presented perspective is that of the public sector practitioners who are responsible for the management of flood risk at the hydrographic basin scale. The position of each basin in Figure 12, given by the respective membership crisp value, represents more a prioritization of strategies than an "all-or-nothing" type interpretation, meaning that none of the strategies should be completely disregarded in favor of the others.

The territorial dynamics and the flood impact pattern of the Mondego basin would require comparatively less resources, *i.e.*, low capitally intensive solutions, but of rapid implementation due to the high severity of impacts, such as early warning systems. These systems face the constraints of data availability and readiness. In this regard, the PGBH assumes the objective of improving the network of river flow gauge stations—currently, only 12 river flow gauge stations dispose of more than 20 years' worth of records of maximum peak flows (8 in Mondego, 4 in Vouga and none in the Lis). By improving the network of river flow gauge stations, early warning systems can depend less on the meteorological forecast and on data provided by rain gauge stations, and more on real-time river flow data. Along with this priority and based on the availability of resources, emergency strategies must continue to be combined with the other risk management strategies. With time, relocation and other land-use planning measures could also contribute to the reduction of impacts, namely those with severe human consequences—as the DISASTER database mortality figures appear to suggest—by reducing the percentage of urbanized areas in floodplains. For this basin, structural mitigation, as a strategic approach and a hard measure, is the least recommended.

The Lis basin represents somewhat the Mondego basin's opposite context. Lis is marked by comparatively greater exposure, although the impacts are mostly related to material consequences instead of human consequences. Given the small area and the economic vitality of this basin, priority can be attributed to structural mitigation. Structural defenses, such as small dams, can play a moderate role in risk reduction for progressive floods, but in small basins, they can have a significant role regarding flash floods by reducing and delaying flood peak flows. According to the PGBH [29], only one dam in the study area located in the Mondego basin has the capacity to attenuate progressive floods, while the remaining dams, mostly located in the Mondego basin as well, can act during flash floods. The obtained results may indicate that the decision-makers of the Lis and Vouga basins can ponder to articulate this type of strategy with other regional water resources strategies in the energy sector, for example. Nevertheless, a strategy that relies on demanding an allocation of resources must be compatible with medium- to long-term emergency and land-use planning.

Finally, the Vouga basin constitutes an intermediate situation. This basin is less impacted in terms of the number of E & D persons per 105 inhabitants and the total number of OHC and OMC per km^2. The flood risk management strategy may rely on hard and soft measures, but the urgency in action is more similar to the urgency in the Lis basin than with the Mondego basin.

Both of the F-N curves (*cf.* Figure 5) support the information that was obtained through the fuzzy logic analysis, contributing to the differentiation of selected basins with potential implications in risk management. For example, the Vouga and Mondego basins exhibit identical behavior in terms of occurrences with D & D persons but are distinguished by the different magnitudes of evacuated and displaced persons. This difference is expressed in the distinct position of these basins in Figure 12, with the Mondego basin requiring more immediate management responses (*i.e.*, shorter in terms of time). The Lis basin is less severe in terms of human consequences (OHC) but is relatively more severe in terms of material consequences (OMC), which is why it is positioned in Figure 12 as longer in time (lesser urgency) but requiring more resources because of the greater exposure (*cf.* Table 3 and Figure 8).

At a different perspective and scale from the one that is presented in this paper, [45] also investigated the appropriateness of risk-based flood hazard management strategies. The sources, pathways and receptors of the hazards that they considered can be equated to the characterization of the territorial context that was performed in our study, while the focus on the "harm" or impact is equally crucial in both.

5. Conclusions

This study demonstrates the applicability of flood impact databases in the appraisal and management components of flood risk governance, going beyond the assessment of individual and societal risk. The potential for their coupled use with data that express the territorial context of each basin was exemplified and, based on such results, the application of fuzzy logic analysis allowed the identification of specific priorities of action in flood risk management.

Methodologically, the analysis of the flood impact database and the territorial context allow for the differentiation of three contiguous basins that are part of the same water management planning instrument, the PGBH. Such distinct behavior results in contrasting fuzzy membership values in regard to the criteria of time and resources, which supports the prioritization of specific flood risk management strategies. Fuzzy logic analysis could have considered other decision-making criteria, such as the implementation cost, legal complexity, institutional capacity or durability, although, to some extent, these criteria depend ultimately on time and resources.

The results show that the Vouga, Mondego and Lis basins behave differently in terms of flood impacts, both when impacts are distinguished between human and material consequences as well as when they are analyzed together. The observed patterns of flood impacts appear to be more related to socioeconomic factors than to biophysical factors.

The European Union Floods Directive requires member-states to elaborate flood risk management plans until the end of 2015, which must articulate with other sector planning instruments related to water resources, conservation, spatial and emergency planning. The methodology presented in this manuscript can provide a holistic and regional approach in supporting decision-making, based on a long record of flood impacts and on socioeconomic and geophysical data. The coupled analysis of impact databases with territorial analysis can, therefore, contribute to improve the knowledge and management of flood risk.

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Author Contributions

The methodological approach was designed and written by the two authors. While data collection, statistical analysis and figures were conducted by Pedro Pinto dos Santos, the introduction, the discussion and conclusions were discussed and written by the two authors.

Conflicts of Interest

The authors declare no conflict of interest.

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Paper 13: Flood risk governance towards resilient communities: opportunities within the implementation of the Floods Directive in Portugal

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ABSTRACT

Flood risk governance is undergoing a step forward with the implementation of the Floods Directive, which extends to all EU member States a standardized approach to assess and manage flood risks, with a strong focus on public participation. This normative document constitutes a considerable development in terms of flood risk policy in Portugal, which should be fully taken as a tool of resilience building.Resilience, however, is a very complex concept which involves the capacity of communities to prepare, adapt and respond to disasters. Whatever the nature of these changes, resilience is present in any risk governance process. After a brief discussion on what practices and policies make a flood resilient community, the goals and methodologies expressed in the Floods Directive, and its Portuguese transposition, are analyzed in the way they contribute or conflict to the goal of achieving more flood resilient communities. A reflexion is made about the consideration of resilience in three important issues of the directive: the risk assessment phase, which culminates in flood risk maps, the management phase to be conducted upon flood risk management plans, and the participation and communication which should be present in all of them.

Keywords: Floods Directive, resilience, risk assessment, risk management, community participation.

INTRODUCTION

Based on the EM-DAT database from 1980 to 2007, estimations are that climate-related disasters will affect[4] about 375 million people in 2015 (Ganeshan & Diamond 2009). In 2012, floods alone were responsible worldwide for 53% of the 139 million people affected by natural disasters, and for an estimated damage of US$ 25.6 billion from a total of US$ 157.5 billions (CRED 2014). Floods, like other natural hazards, are unavoidable but their impacts can be considerably lessened which motivates stakeholders and communities to be more preventive than reactive (Alexander 2012). In general terms, independently of the nature and type of risk - whether natural, social or technological – a preventive *ex-ante* approach is favoured by several factors such as a heightened awareness and acceptance of risk. This is applicable to FRG in Europe where climate change models predict an aggravation of meteorological risks such as floods and storms (Birkmann & von Teichman 2010). The estimated number of affected people shows an increasing trend and decision-makers are realizing that reducing vulnerability is preferable to emergency response (Alexander 2012). A reduction of vulnerability constitutes in fact a condition for increasing resilience. In a broader sense, if a risk governance process doesn't address the social and environmental problems that characterize a given community, then it might fail in developing greater flood resilience. Resilience levels do become evident after a shock

[4]To be affected means to require immediate assistance during a period of emergency, i.e. requiring basic survival needs such as food, water, shelter, sanitation and immediate medical assistance (CRED 2014).

(Figure 1) but this capacity of dealing and recovering from impacts requires a well-developed and executed risk policy that privileges an *ex ante* disaster approach. In fact, the initial condition of a community is something that is built before the hazard event.

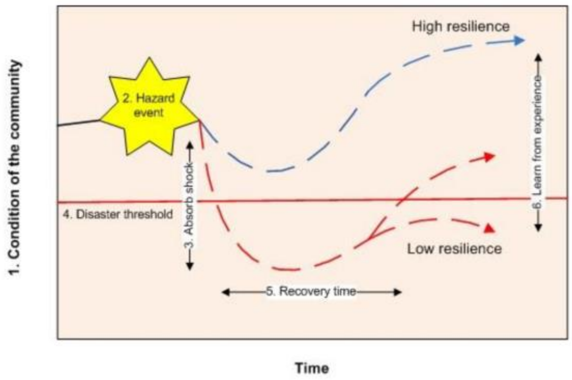

Figure 1 The importance of community resilience in determining the recovery time to a hazard event (Haigh 2010)

The Floods Directive (EU 2007) provides a framework for addressing flooding across Europe. Assuming knowledge, organisation and communication as key resources in risk management (Fothergill, cited in Alexander 2012), this essay attempts to contribute to debates on the role of the Floods Directive and its transposition into the Portuguese legislation, in terms of building more resilient communities. The analysis will be divided in the assessment, management, communication and participation spheres, as they are approached in these two documents.

FLOOD RESILIENT COMMUNITIES

The definition of resilience adopted by the United Nations International Strategy for Disaster Reduction (UNISDR) states that resilience is “the capacity of a system, community orsociety potentially exposed to hazards toadapt, by resisting or changing in order toreach and maintain an acceptable level of functioning and structure” (UN 2005, p. 4).The UNISDR stresses that this capacity is a function of the“degree to which thesocial system is capable of organizing itselfto increase its capacity for learning frompast disasters for better future protectionand to improve risk reduction measures” (UN 2005, p. 4). This concept is wide spread but is not the unique and some authors discuss the readiness for operational use of the different concepts (Gallopin 2006; Klein, Nicholls & Thomalla 2003).

Regarding urban resilience in particular, The World Bank (WB 2013, p. 7) presents a definition similar to the UNISDR, stressing the capability “to prepare for and respond to the risks and impacts”. This WB report on the investments of the institution in partner countries regarding disaster risk management and climate change adaptation points out the measures that are part of resilience building: (1) soft measures such as land use and urban planning, community awareness and preparedness, monitoring of hazards and risks, early warning systems, emergency and evacuation plans; (2) hard measures such as retrofitting of critical infrastructure, adapting buildings and urban spaces, managing retreats and relocation and maximization of eco-systems services.

The campaign “Making Cities Resilient” (UN 2014) identifies the characteristics of resilient communities: ability to avoid disasters by improvement of infrastructures, services and building codes; ability to anticipate disaster and protect assets; local government engagement in sustainable urbanization and community participation;

adequate understanding of risks both by local authorities and communities; public participation in the decision-making process, and the local knowledge is valued. As stated by Manyena (2006), it seems consensual that in order to adapt to adverse circumstances, a disaster resilience programme will have to aim at enhancing not only the assets and resources, as well as the understanding about the communities' culture, particularly its "non-essential attributes" (Manyena 2006, p. 439), i.e., those that the community is willing to change in order to adapt and survive.Similarly to other natural hazards – earthquakes, for example – floods can generate disastrous direct and indirect effects whose severity can be even more serious than the direct flooding itself (Messner & Meyer 2006). This fact implies largely that a resilient community to flooding must ideally be a resilient community to hazards in general. Nevertheless, specific characteristics of flood resilience can be found and pursued. In the flood management cycle Schelfaut et al. (2011) highlight that the association of knowledge and awareness is the basis of a flood resilient community.

Community-level flood protection schemes like storage basins, raised river embankments, coastal defences, maintained river channels, floodwalls and barriers can be a first line of hard defence against flooding (Ingirige & Amaratunga 2013), although they intervene more on the flood hazard than on the flood vulnerability dimension. Ingirige and Amaratunga (2013) describe findings from research projects in UK and Bangladesh where non-structural measures for improving flood resilience are pointed out, namely insurance and early warning. Parker, Tunstall & McCarthy (2007) alert for technical, social and institutional aspects that must be accounted for in order to make early warning effective and inclusive of lower social grades. Both studies point out the need for multi-sector and multi-level approaches, for example, in allowing the contingency of socioeconomic routines and by involving non-civil protection actors to assure the effectiveness of evacuation and emergency response operations. Capacity building is also assumed as a critical factor in flood resilience (Ingirige & Amaratunga 2013) – the success of non-structural measures in addressing flood resilience depend on high levels of capacity building because they require multi-stakeholder communication at different geographical scales and decision levels (Schelfaut et al. 2011) along with enhancing perception and risk communication, early warning systems and management plans.

In this brief contribution, it seems clear that flood resilient communities are those supported by FRG policies which assume multi-scale, multi-stakeholder and transdisciplinary approaches as premises for assessing both "constructivist" and "realist" visions of risk (Klinke & Renn 2002). Only upon this wide basis of knowledge, perceptions and inclusion can risk management be effectively conducted.

BUILDING RESILIENCE WITHIN THE FLOODS DIRECTIVE FRAMEWORK

The European Union Directive 2007/60/EC on the assessment and management of flood risks (the Floods Directive) is establishing a new framework for the reduction of their adverse consequences in human health, environment, cultural heritage and economic activity. The framework is organized sequentially in three phases: preliminary flood risk assessment, flood hazard and flood risk mapping and flood risk management. Each phase is subject to a review and update process every six years. The Portuguese transposition of the directive was performed by the Decree-Law 115/2010 of 22 October 2010 (DL 115/2010). FRG was never before performed with such specificity in the Portuguese context making relevant to analyse how the proposed framework deals with the complexity, uncertainty and ambiguity inherent to flood risk, and how risk-based, precaution-based and discourse-basedmanagement models are considered (Klinke & Renn, 2002). Portuguese literature on this subject is very scarce. The Floods Directive itself is only on its first stages of implementation, this means, flood risk mapping is not yet concluded. Figueiredo et al. (2009) studied flood risk social perception and its degree of incorporation into management mechanisms and found that the "overriding tendency is to underestimate the contribution of social actors in light of technical and scientific views" (p. 597).

The assessment sphere of flood risk governance

Within this sphere the potential to build resilience in a given territory and community lies highly is the last part of the resilience definition provided by the UNISDR, highlighting the importance of "learning from past disasters for better future protection". The absorption capacity mentioned in Figure 1relies also in better knowledge of the flooding historical records and processes, better awareness of potential flood losses and vulnerability and its integration into decision-making.

The preliminary flood risk assessment foreseen in the Floods Directive, and already concluded by the Portuguese government, assumes a precautious attitude by considering "potential risks", i.e., not only areas where flood damages have occurred in the past may be considered, but also areas where flood damages are currently unknown but may potentially occur. Methodologies which categorize the susceptibility of a basin's stream network to flooding (e.g. Reis 2011) as well as geomorphologic analysis play an important role in the identification of such areas. Upon identifying these areas, flood hazard maps are produced for three probability scenarios: low, medium (likely return period ≥ 100 years) and high probability. Flood hazard can be assessed through a diversified set of methodologies from which the most used are those based on historical, geomorphologic, hydrological and hydraulic techniques (Díez-Herrero, Laín-Huerta & Llorente-Isidro 2008). What seems to be clear is that a reduction in uncertainty about flood extents and probabilities is achievable when the different approaches are used complementarily to each other (cf. good examples in Benito & Hudson 2010). A positive aspect is the fact that no methodology for hazard mapping is disregarded or made preferable. Santos, Tavares & Andrade (2011) exemplify benefits of using different flood hazard mapping methodologies complementarily, such as a better understanding of the flood processes, with hydrologic and hydraulic methodologies presenting advantages in modelling recent or future changes in the basin and floodplain, while geomorphologic methodologies are advantageous in reliability about longer term planning because they are based in past flooding evidences.

Regarding the vulnerability assessment, the DL 115/2010 details a bit further what is mentioned in the Floods Directive. Both say that risk maps must list the potential adverse consequences associated with the three probability scenarios and identify (i) the indicative number of potentially affected people, (ii) the critical buildings and (iii) the economic activities potentially affected, particularly the critical infrastructures. These items refer exclusively to the identification, by overlay, of exposed elements. The Portuguese transposition only discriminates with more detail these elements, such as contaminant sources, hazardous substances, protected natural areas, lifelines, cultural heritage and areas where a significant solid and debris flow can be expected. A more detailed assessment of social, physical and economic vulnerability would be advisable. Regarding this insufficiency, methodological and conceptual constraints can be found that maintain a technocratic approach in flood risk policy (Jeffers, 2013). The first ones include an excess of confidence in the ability to quantify physical exposure and the unfamiliarity with vulnerability assessment methods – and its applicability to public policy (Mustafa et al., 2010). Conceptual constraints derive from a biased understanding of flood risk and its causes, which assumes that losses can be eliminated by preventing the flood itself (Jeffers, 2013).

In the Portuguese context, vulnerability assessments are not abundant and the public tendering procedure for the elaboration of flood risk maps prioritizes a quantitative analysis of exposed elements, not vulnerability, of four types: human damages, expressed in terms of affected people; cultural heritage damages; economic damages, calculated in function of land use classes; and environmental damages, based on the presence of the critical and sensitive elements mentioned above. A thorough "understanding of exposure to the hazard, characteristics andpatterns of vulnerability, and the relationshipbetween different stakeholders in the perception offlood risk" (Brown & Damery 2002:424) was presented as valid for the UK, and could be valid for Portugal in the basis for a broader and long-term perspective of FRG.

The management sphere of flood risk governance

Flood risk is under the competency of the Environment Portuguese Agency (APA) as the national water authority. The DL 115/2010 creates a National Commission for Flood Risk Management (CNGRI) in which the APA, the civil protection authority, the cartographic institute and municipalities are represented. In terms of implementation, in February this year, the APA has launched the public tendering procedure for the elaboration of risk flood maps, to be concluded in 5 months but no decision about the winner/s was yet taken. This can constitute a delay in the design and implementation of flood risk management plans (FRMP). According to the directive, FRMP's will be designed for management units where potential risks were previously identified and mapped. Scale of FRMP is an important issue because it implies decisions regarding resource allocation, type and number of involved public and private stakeholders, and strategies of community participation. In Portugal, risk management is essentially based in municipal plans although top-down logic prevails in the policy making and distribution of resources (Tavares & Mendes 2010). Such approach results in lack of attention to local specificities, exemplified by municipalities where flood risk management privileges the main water courses against the flash and urban floods that occur in smaller streams, but whose impact is also relevant due to its frequency, unpredictability, human and material losses. As it was demonstrated in Sultana, Thompson & Green (2008) research, an institutional building following a bottom-up approach, i.e., from the settlement to the catchment scale, might allow a better achievement of the Floods Directive objectives.

From a sector and actors' perspective, the Floods Directive states that FRMP's must consider aspects such as"(...) costs and benefits, flood extent and floodconveyance routes and areas which have the potential toretain flood water, such as natural floodplains, the environmental objectives of Article 4 of Directive 2000/60/EC, soiland water management, spatial planning, land use, natureconservation, navigation and port infrastructure" (cf. Article 7(3)). Such articulation is resumed for the Portuguese context in Figure 2. Inside the Portuguese legal framework for spatial planning, FRMP's are classified as sector plans (cf. Article 12 of DL 115/2010). With this status, they must be in accordance with the top management instrument, the National Program for the Spatial Planning Policies (PNPOT), from which FRMP's receive primary guidance and with regional plans for spatial planning (PROT).

Hydrographical Basin Plans (PBH), some of them under revision, must be in "close articulation" with FRMP, and their chapters on flood risk assessment must "respect the criteria and goals" of the DL115/2010. Regarding local and special spatial planning instruments (PMOT and PEOT), they must adapt to the content and guidelines in vigor under FRMP's. This is also applicable to the Ecological National Reserve (REN), a special legal figure to protect ecological values at the national scale, which must be altered in function of what is established in FRMP's. The preamble of the DL 115/2010 says that FRMP's must "take into account the characteristics of the zones to which they refer and predict specific solutions for each case" as well as consider what is disposed in the emergency planning instruments (PEPC). The Article 12(3) clarifies that PEPC shall "warranty the due compatibility with FRMP's" so the relation is two-sided. Finally, the dispositions of the DL 115/2010 don't prejudice the dispositions of the DL 364/98 – this decree-law obliges municipalities with historical records of flooding in urban areas to elaborate flood hazard maps with the objective of defining restrictive land uses. The revocation of the DL 364/98 is not foreseen, although it could be – particularly after the completion of the FRMP's – for the following reasons: the flooded areas delineated upon the DL 364/98 will naturally be included in the Floods Directive preliminary assessment, and consequentially, in FRMP's; not revoking will create duplication and/or contradictions between risk management measures defined in both documents; risk classifications and assessment methodologies may not concord in several situations raising ambiguous interpretations of the same realities.

The introduction of the concept of "deliberate over-flooding" is foreseen in the Floods Directive which is an innovative measure in the Portuguese context, although experiences already exist in some European countries (Erdlenbruch et al. 2009). Deliberate over-flooding consists in deliberately causing flooding in upstream areas – for example, deriving flow to natural storage areas – in order to reduce and delay the peak flow in downstream areas. This practice allows transfer risk from areas downstream (e.g. urban settlements) to less vulnerable areas upstream. Financial compensatory measures can be defined to make this practice appealing to over-flooded areas. If well designed and implemented – technically, socially and financially – this practice can become an important measure in increasing flood resilience.

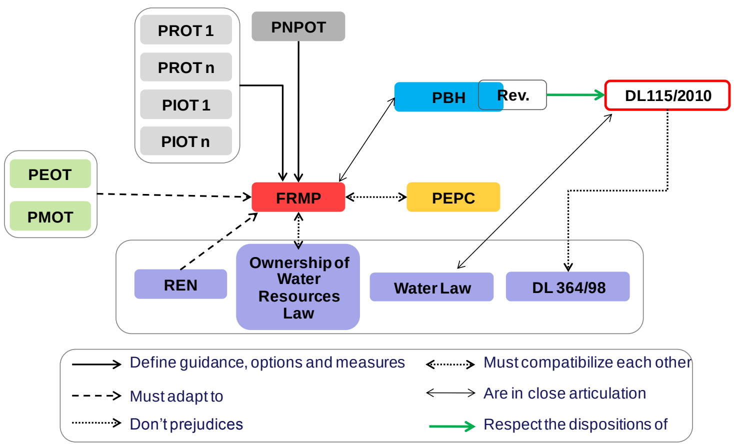

Figure 2 Articulation of the FRMP according to the Portuguese transposition of the Floods Directive.

More clearly than the Floods Directive (cf. Article 7(3)), the Portuguese transposition privileges the option for non-structural measures of risk reduction in FRMP's. Integration of flood risk management with other sector planning instruments is one of the possible ways to pursue this preference, taking advantage of the potential synergies.

It is therefore positive that the Floods Directive refers the need of integrating strategies with the Directive 2000/60/EC (Water Framework Directive) and with spatial planning instruments. The methodological findings of research projects such as the STAR-FLOOD (Hegger et al. 2013) and the CRUE-ERAnet (e.g. Jobstl et al. 2011) in what concerns the selection, monitoring and evaluation of flood risk structural and non-structural measures can provide useful insights for FRMP's.

The Portuguese context of flood risk management may present differences from that of other European regions. The separation between water and people that is observed in some European countries caused by heavy structural measures (e.g. Kelman & Rauken, 2012 and Jeffers, 2011) has not occurred in Portugal. The countries studied in the STAR-FLOOD project present, until recently, a technologically oriented approach to flood management (Hegger et al. 2013) while this may not be the case in Portugal, or at least with the same magnitude. In fact, dams and stream channelization do exist in a few basins but a comparison of their role and the role of non-structural measures in reducing flood damages – particularly spatial planning – are still to be thoroughly assessed. The two opinions on FRMP's that municipal authorities present in Germany (Heintz, Hagemeier-Klose & Wagner 2012) – one holistic, which combines structural and non-structural measures upon a risk governance approach, and another which maintains a focus on local, short-term solutions marked by a security approach – are also present in Portugal, perhaps more evident about coastal than fluvial floods. Regarding this later type of floods, although the lack of research in this area, it seems plausible to think that the role of local administrators in the fields of spatial planning and civil protection, along with the scarcity of financial resources for structural defenses, can justify the minor relevance of structural solutions in Portugal.

Participation and communication in the Floods Directive

If the process of gathering knowledge about flood risk was conducted with participation of stakeholders and communities, its management should also be carried out in a participatory way. This aspect is given top relevance in the Portuguese transposition of the Floods Directive, where Article 14(2) elaborates that FRMP's elaboration, re-assessment and updating must be conducted with the "active participation of all interested parts". It is, therefore, pertinent to envisage how this participation can be planned and put to practice with the public and private sector.

The model of cooperative discourse (Aven & Renn 2010) has the advantage of incorporating several mechanisms of participation and encouraging mutual learning. It is marked by great versatility in coping with the plurality of knowledge and values at stake in FRG, namely, the proposal of different participation tools according to the type of risk. When risks are marked with high complexity, epistemic tools are more adequate in order to deal with scientific and technical expertise. Examples of tools consist in expert auditions or Delphi and Group Delphi dynamics. When risks are marked with high uncertainty – equity and sharing of costs and benefits are in discussion – reflective discourse instruments such as stakeholders' auditions, round tables, and mediation and arbitration dialogues are suggested. When ambiguity is prevalent in decision-making – values, social or moral justification are in discussion - a participatory discourse is present, and the adequate instruments of participation include citizen panels or juries, public consensus conferences or citizen actions groups. If one looks, for example, at the "deliberate over-flooding" practice, it's easily recognizable the relevance in applying all of the three types of discourses given the technical-scientific complexity, potential conflicts of interest and values at stake (cultural, ecological, etc.).

Risk communication is an important part of community involvement. Effective risk communication promotes a risk culture and leads to greater opening and easiness in reaching agreements on management strategies. Risk communication should be tailored to the specific needs of the population, giving each individual the opportunity to judge for them the level of risk which he/she is facing and to make his/her own decisions on the measures of protection and preparedness (Kellens et al. 2009). Maps, as communication tools, play a crucial role in flood risk communication. The three flood probability scenarios foreseen in Article 7 of DL 115/2010 shall be clearly explained, particularly, given the difficulty in conceptualizing the low probability and highly burdensome flood events (Keller , Siegrist & Gutscher 2006), for which the conceptual model of risk map developed under the RISKCATCH project (Spachinger et al. 2008) could be useful. FRMP's shall ponder other communication tools such as WebGIS and their ability to include real time data and population warnings. The creation of a national flood early warning system (cf. Article 11 of DL 115/2010) is a positive aspect of the transposition. The system already existed and provides real time data on rain, flow and dam level in the main Portuguese basins.

CONCLUSIONS

The presented essay argues that the process of building flood resilience begins with the capacity of generating better knowledge about the hazard itself and its consequences upon vulnerable communities. The increase in the capacity of systems to prepare, adapt and respond to hazards starts with a thorough assessment of flood risk and knowledge transfer, as basis for an efficient management. Building resilience specifically to flood risk contributes to a general improvement of resilience to other risks. The transposition of the Floods Directive into Portugal resulted in a robust document in its goals and potential lines of action, and consequently, with a range to decisively contribute to reduce flood losses. Nevertheless, some issues still need to be further studied: participative models in the several phases of the FRMP; financing mechanisms; articulation with other sector planning instruments; and goals and methodologies for performing cost-benefit analysis and monitoring.

An important aspect of community's participation in the process of risk management consists in finding a balance between an essentially sociological view and a vision focused in the physical processes of the hazard – summarized by Klinke & Renn (2002) as "realism" versus "constructivism". As to FRG, it is assumed that the dynamic nature of the risk requires an equally dynamic strategy of management. The elaboration of FRMP should incorporate this principle, focusing on both bio geophysical and socioeconomic specificities of the different hydrographic management units. Methodologies for assessing risk tolerability and regulatory strategies as ALARA ("as low as reasonably achievable") or BACT ("best available control technology") may be beneficial. Methodologies for evaluating resilience (Cutter, Burton & Emrich 2010) could also be included. Dealing with the biophysical and engineering aspects of flooding and the institutional and social landscape of risk management is perhaps one of the greatest challenges to the best application of the Directive. The Floods Directive assumes a simple but relevant step forward in FRG – the assumption that floods are "natural phenomena which cannot be prevented" (EU 2007: preamble (2)), but their impacts can be reduced and mitigated, and their aftermath better overcome. Considering its goals and provisions, the Floods Directive is capable of contributing to build more resilient communities.

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